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PREFACE

This proceeding includes papers presented at the Second U.S./USSR Symposium on Comprehensive Analysis of the Environment. All the papers, except for one, were given in English or Russian at Honolulu, Hawaii, USA between October 23, 1975 and October 25, 1975. The paper by Gerasimov, Izrael, and Sokolov was given in New York on October 20, 1975 at a joint meeting with Biosphere Reserves Project.

The publication of these proceedings is in accordance with the Memorandum of the Fourth Meeting of the U.S./USSR Joint Committee on Cooperation in the Field of Environmental Protection, signed in Washington on October 31, 1975, which called for independent publication in both the United States and the Soviet Union.

INTRODUCTION

The Joint U.S./USSR Committee on Cooperation in the Field of Environmental Protection was established in May 1972. These Proceedings result from one of the projects, Project VII-2.1 *Comprehensive Analysis of the Environment*, derived from the formation of the Joint Committee.

The project derives its strength and value from the idea that it is important for scientists who share a concern for the environment to take a broad look at the subject and to exchange views with their colleagues. It is hoped by this process to help assure that the overall goals are not lost in the clutter of minutia. These Proceedings cover the Second Symposium held by the Project on the general theme of *Maximum Acceptable Environmental Stress on Organisms, Populations, Ecosystems, and the Biosphere as a Whole*. I think that the quality of the papers was extraordinarily good, and I here thank again all the participants for the effort they made. I would like to especially thank my Project Co-Chairperson Izrael (and also the Soviet Chairperson of the Joint Committee) for bringing with him a group of such excellence.

Roger S. Cortesi
Chairperson U.S. Side

ACKNOWLEDGMENTS

Yuri A. Izrael and Roger Cortesi were Chairpersons of this project, *Comprehensive Analysis of the Environment*, and they were responsible for organization of the symposium.

Special credit must go to William Brown, Special Assistant to EPA Administrator Russell Train, for the U.S./USSR Environmental Agreement, for advice and help in carrying out the symposium, and to John Dovel of EPA for skillful handling of countless and often exasperating details.

GENERAL APPROACHES TO THE PROBLEM OF MAXIMUM PERMISSIBLE LOAD ON THE ENVIRONMENT

YURI A. IZRAEL

The concept of the permissible load on the environment is extremely complex and ambiguous. In attempting to formulate a definition of the permissible load, we are faced with completely natural questions. What determines the permissibility of the load? Is it the lack of any changes in the environment or only undesirable changes? If they are undesirable, then for whom? Is it for an individual or for the components comprising the natural ecosystems of the species and population of animals and plants or is it for the biosphere and mankind as a whole?

Which effects are we discussing? Those which are natural, where the environment changes slowly and evolves, or those which are artificial (anthropogenic) where nature can change quickly and even deteriorate?

Let us attempt to formulate the approaches to the problem of permissible loads, their effect on the environment from the point of view of ecology, keeping in mind the *anthropogenic* planned or unplanned effects.

To begin with, let us attempt to define the qualities of the environment since, at the present time, a generally accepted definition does not exist.

It is also necessary to define the initial, or base line, in order to begin a calculation of the state, at the present time, or for example, the state prior to the beginning of the intrinsic anthropogenic effect.

Without laying claim to a complete understanding of the environment, we assume that the high (or sufficient) quality of the environment, for the specific ecosystem, implies: a. the potential for the stable existence and development of the given, historically developed or created, or transformed by man ecological system, in a given point or area; b. the absence of unfavorable consequences for any (or the most important), and primarily human population located in that area either historically or temporarily. In this instance it is possible to examine the quality of the environment for the particular population.

Biological (ecological) criteria exist and can be defined to show the high quality of the environment: high biological productivity, optimal correlation of the species, biomass population, located at various trophic levels and so forth (see for example [1]).

In the broadest sense, we understand the permissible anthropogenic load on the environment to be the load (composed of individual, uniform and heterogeneous actions) which does not change the qualities of the environment, or change it within the permissible limits; that is, does not result in the destruction of the existing ecological system and the appearance of unfavorable consequences among the most important, and primarily human, populations.

In our opinion, all ecosystems of the biomass can be conditionally divided into two categories:

—unique or prohibited areas where fallout of any sort is forbidden; natural ecosystems where it is incumbent to observe the basic requirements to maintain the ecosystems and the high quality of the environment, but where certain individual changes are possible (large forest areas and seas);

—zones with heavily transformed ecosystems or artificial ecosystems (agricultural areas, cities, canals or rivers, and so forth).

However, the question arises whether it is possible, while maintaining the regulations, to permit the complete destruction of individual species without violating the viability of the ecological system. Thus, it would seem that the destruction of individual organisms on Lake Baykal would be a catastrophe for the unique ecosystem of the entire lake.

In our opinion, in determining the permissible load, it is necessary to adopt as the base, the significance of the function of the state of the biosphere, which at the present time is not affected by local influences.

It is necessary to take into consideration the state at all stages of the individual, population, community, ecological system and finally the biosphere as a whole.

Let us introduce a certain function of the state of the ecosystem or of another element of the biosphere (characteristic of, for example, the volume of the biomass, productivity, metabolism, energy exchange in the system, or a combination of these and other analogous factors):

$$I(\overleftarrow{R},t)$$

(converted in space and time), or a generalized function for region

$$I^{*}(t) = \int_{\overleftarrow{R}} I(\overleftarrow{R},t)\,d\overleftarrow{R} \qquad (1)$$

This function may be recorded for the ecosystem as a whole, or at any stage of any population, and then examined within its permissible limits.

Let us introduce the function of the artificial influence which is capable of changing the state of the ecosystem under study:

$$H(\overleftarrow{R},t)$$

or:

$$H^{*}(t) = \int_{\overleftarrow{R}} H(R,t)\,d\overleftarrow{R} \qquad (2)$$

Then:

$$I^{*}a(t) = I^{*}(t)H(t) \qquad (3)$$

describes the change in the state of the elements of the biosphere under the influence of the artificial factor (Figure 1).

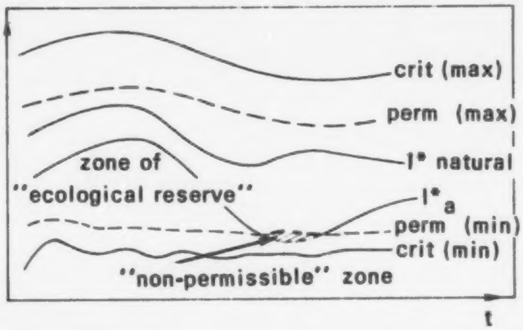

Figure 1. Biosphere elements changed by artificial factor.

Apparently, it is possible to determine the critical and permissible values of functions $I_{crit.}$ and $I_{perm.}$ which must differ from each other.

It can be seen from Figure 1 (which illustrates these changes), that in the majority of cases $I_{crit.}$ has two sets of values: maximum and minimum, while the permissible values lie in between; a change of I from time is determined by a change in the external factors such as: temperature, humidity and so forth.

The difference between the actual and permissible state (as well as at times, the critical) is the ecological reserve of that system. By comparing these curves it is easy to find the "critical" zones and to determine priorities in locating the most stressed situation and in adopting the appropriate and most important measures.

Analogous curves may be examined, as well, for the function of action determined, from the curves, the "critical" zones and "reserve" zones (Figure 2).

Minimum and maximum critical levels exist for many of the action factors, while the optimum value lies in between. The difference in the values of the permissible $H_{perm.}$ and critical $H_{crit.}$ action factors may (or should) be quite significant. Thus, for certain fish populations this difference for pesticides is found in the interval of $2\text{-}2.10^{3}$, for heavy metals $10\text{-}10^{3}$ [2] and for man, for gamma irradiation, this difference reaches 10^{4}.

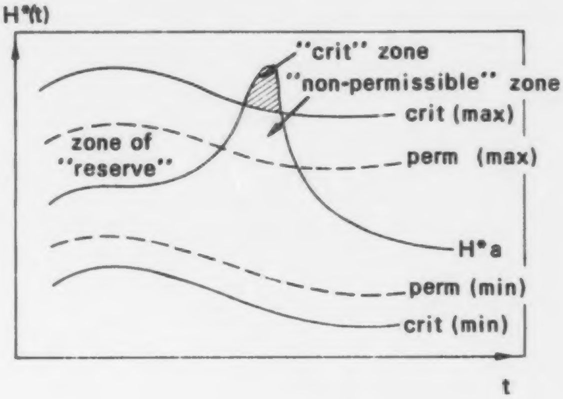

Figure 2. Curves for the function of action.

The above-mentioned curves can be plotted for various media and pollutants. Such an investigation is equivalent to a study of various limiting factors for some populations or ecosystems within the appropriate tolerance range.

Formulation of the permissible or maximum permissible load, its theoretical and experimental calculation, are necessary for the solution of a number of problems and employment in various areas:

- —designing and implementing economic development, construction of cities, recreational development in the specific area;
- —determining priorities in the activities designed to protect man and his environment in zones of intensive man-made action;
- —defining the economic consequences of the actions and measures directed toward reducing such actions;
- —providing optimum monitoring systems for the environment.

Of course, the enumerated tasks are in a majority of cases closely linked; the solution of each of them calls for certain results obtained during the solution of other problems.

Let us examine the approaches to a determination of permissible loads, in accordance with the indicated spheres of application.

It appears to us, that maintenance of a sufficiently high quality of the environment requires:

—for the normal functioning of the ecosystem—not exceeding the maximum permissible ecological load (MPEL) for the specific ecosystem. In reaching this value, accounting must be made of all the factors of the combined and complex actions on the ecosystem. Efforts in this direction are underway; however, such values still have not been calculated even in the form of examples for individual regions;

—for assuring the absence of undesirable consequences among individual populations—not exceeding such values which provide the high quality of the environment for the *specific* population either directly [for example, the maximum permissible concentration (MAC)] for man, secondary standards for vegetation and so on, or for the entire ecological chain, having direct significance for the specific population (for example the MPC for individual species of catch fish). A substantial volume of material of a scientific and technical nature is available in this field. The USSR has developed MPC values for hundreds of ingredients for man and certain other populations.

Development of the MPC for individual populations began significantly earlier (thus, the MPC for man underwent development in the USSR in the thirties). This work is somewhat simpler than the development of ecological norms since, in essence, it includes only some of the elements of the work which must be carried out to determine permissible conditions for the ecosystem as a whole.

However, the situation has already pointed out the need for carrying out the work and implementing ecological norms.

Thus, development of permissible man-made loads on the ecosystems of unique natural objects is practically necessary, for example, the unique ecosystem of Lake Baykal. However, differences still exist in the approaches to the development of the MPC and MPEL values. In computing the MPC, the permissible values were taken from values of concentrations where the population did not manifest either any harmful, undesirable pathological effects or any noticeable reaction. The difference between the MPC value and the maximum critical values of concentrations of the maximum critical concentrations (which can be lethal for certain individuals) reaches significant values (as noted above). Of course, this difference assures a large reserve of "stability" in the population while adhering to the MPC, or even during slight excesses of the MPC values.

The values of the MPEL are currently based on an understanding of the resistance of the ecosystem, or the critical state of the ecosystem or of its individual links and levels. In this instance, the reserve of stability is absent — upon attaining the MPEL, the ecosystem may begin to disintegrate. Of course, in this instance, as well, it is possible to introduce the concept of the permissible ecological load (PEL) based on like concepts of the MPC. An example is the introduction of obligatory adherence of the MPC for all links in the ecosystem or even a certain "complex" MPC, taking into account the interaction among separate populations. At that point there also will be a reserve of stability (an ecological reserve) formed on the basis of the difference between the PEL and MPEL (as demonstrated in Figures 1 and 2).

If the MPC were originally worked out and implemented for man then, in developing the MPEL, the question arises as to priorities, which ecosystems and which locations (areas or regions) require the greatest effort in raising the quality of the environment.

The question is also raised as to how the priorities are set with regard to the factors of action, sources of action, sectors of industry and so forth.

It is obvious that if the load exceeds the permissible point, the man-made action will cause harm to the population, ecosystem and biosphere as a whole.

As previously referred to [3], it is possible to distinguish provisionally the ecological, economic and esthetic damages. Unquestionably there is a link between the designated forms of damage and, in particular, the ecological and economic.

It is not difficult to assume that ecological losses are in direct relation dependent on the degree of action of various factors on the biosphere.

Generally, when the ecological losses for the m population (noted in a simplified form, see [3]):

$$Am(t) = \int_{\overleftarrow{R}} \sum_{ij} \sigma_{ij}(\overleftarrow{R},t) E_{ijm} N_m(\overleftarrow{R},t) d\overleftarrow{R} \tag{4}$$

where σ_{ij} is the concentration of that pollutant i in that medium j, E_{ijm} is the toxicity of the specific ingredient for m population, N_m is the number of organisms of the specific population; while σ, in turn, is the function of the sources and hydrometeorological conditions; then the priorities are factors for which A_m attains maximum values under varying conditions.

Obviously, the study of the effects directly on man must be given the highest priority.

For example, when dealing with regions, the highest priority must be assigned to cities as well as zones which provide drinking (potable) water; for the media, air and fresh water wells; by pollutant (for air particulates) sulfur dioxide, carbon monoxide, nitric oxide; for water — biogennic products, phenols, etc.; for sources of pollution for example in cities, thermal electric power stations, boilers and motor transport.

These curves may also be used for economic calculations, superimposing on them economic conditions and searching for optimal results.

The enumerated examples point up the diversity of solutions in determining particular priorities.

The setting of priorities in the calculation and implementation of maximum permissible loads indicates at the same time the setting of priorities to protect man and his environment from harmful man-made influences, and also provides a determination of the degree of damage (or presence thereof, in general) of the given action.

It may be that certain man-made actions, under certain conditions, may be totally harmless while under other conditions, and with the same physical intensity, they may result in substantial damage to the ecosystem (here we are dealing primarily with actions not linked to pollution).

This statement is particularly important in defining the strategies of the optimum interaction of man and nature.

In other words the permissible man-made load must not be calculated by using some fixed value, set in perpetuity or so assigned, it is (or may appear) a fixed component of an available time in a specified period, and a natural effect of the reserve of "stability" of the ecological system.

In conclusion, the approaches employed in the development of priorities coincide to a significant degree with the approaches adopted during the development of the optimal system for monitoring the state of the environment.

The basic tasks of the monitoring system include an evaluation of the state of the biosphere, a prognosis of its state, the development of the most significant factors of action including the definition of priorities, and development of the sources of these actions.

This provides the basis for monitoring, which requires the implementation of a search for the critical or most sensitive links in the ecosystem, most nearly characterizing the system and its state, that is, the representative links; and a search for indices most pertinent to the active factors and pointing to the sources of such action.

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ARE WE ON TRACK IN ASSESSING ENVIRONMENTAL STRESS ON MAN?

FRODE ULVEDAL

Are we on the right track in assessing the health impact of the many environmental stresses to which we are exposed? From my vantage point in the Environmental Protection Agency and from what I have heard during the past few days, my answer must be "yes." However, I hasten to say that we are all just beginning on this track, and we have a long way to go before we can truly say we are assessing man's total exposure and his total body burden of pollutants and the resulting health effects.

In our daily lives, we are exposed to a multitude of physical stresses, such as flickering artificial lights, noises of all types (from typewriters to airplanes). We have traffic jams to contend with as we go to work and return home, with the associated stress of auto pollution; the stress at our workplace, whether chemical, physical, or emotional, all these factors must be considered. Therefore, man is exposed to a great variety of stresses *simultaneously,* some chemical, some physical, and some psychological. Man is exposed to chemical agents through food, water, and air; man is also exposed to microbiological agents through the same media. We must, therefore, begin to seriously cooperate in looking at the total exposure and total body burden to which we are exposed during each 24-hour period in the day, for the seven days in the week, for the months, and for the year. In some cases, we must even look at lifetime exposures.

Obviously, I don't have all the answers as to how we can proceed, but maybe I have some suggestions as to how we can start. And, by collectively thinking about this matter, some of the answers may become obvious although the solutions may remain difficult.

Since environmental health-related research activities are the responsibility of many agencies in this country, let me begin by citing examples of interagency agreements which are occurring, but should be widened and formalized.

The Occupational Safety and Health Administration proposed an occupational standard for arsenic in the air at 2.0 $\mu g/m^3$. The water office in the EPA, based on their research, wanted to change the drinking water standard for arsenic from 0.05 to 0.1 $\mu g/l$. By considering the total impact on man's burden and in cooperation with OSHA, EPA retained its drinking water standard for arsenic at the lower level.

The Food and Drug Administration [1] tells us that the average American is now receiving through his diet 70 to 90 percent of the allowable intake of cadmium. The EPA is at the same time exploring the feasibility of using wastewater and sludge on agricultural land for disposal and treatment, and for watering and fertilizing crops. These residues which will be applied to land may contain many unwanted compounds, including cadmium which may be returned to man via the drinking water or his food, whether from meats or vegetables. In other words, man could be exposed to an increased burden of cadmium because of action the EPA might take. However, by cooperative work with the FDA and the Department of Agriculture we learn what crops will not take up cadmium and in what organs of food animals cadmium may accumulate. So, by having three agencies work together, we can minimize the cadmium load in man.

We have set standards for several gaseous and particulate pollutants in the ambient air. However, the exposure we received of these pollutants indoors where we spend 70 percent of our time was inadequately considered when these standards were set. Although we know that when someone is cooking over a gas stove, that person may be exposed to higher NO_x levels than the ambient standard allows. [2] Let me give you an example.

The CHESS studies [3] have clearly associated significantly increased frequencies of acute lower respiratory illness with ambient levels of oxides of nitrogen. Now we have strong indications that increased frequencies of acute lower respiratory diseases are also associated with indoor air pollutants which arise from domestic use of gas for cooking, again this is mostly due to nitrogen oxides [4]. A comparison between families cooking and heating with electricity and families cooking and heating with gas showed that members of the families using gas for cooking reported a significantly higher frequency of acute lower respiratory illness. The greatest excess in morbidity was found among the mothers who would be the most exposed family member. The EPA is now beginning to look at this to assess the effects of total NO_x load.

By this example, I again hope to have illustrated the importance of looking at all of the routes of exposure when assessing the need for regulating a pollutant.

Furthermore, the rugs on which we walk contain, in all likelihood, *pesticides* which are not accounted for when we talk about banning pesticides for outdoor use. [5] (The pesticides were introduced during the processing and manufacturing of the rugs.) Yet, man is exposed to pesticides through air, water, and food as well. Now we are beginning to look at this.

Let us consider noise for a moment. This is another consequence of industrialization and technological development. This pollution seems to have shown an impressive increase in the last years. Numerous authors [6] have shown that noise provokes psychological stress reactions, not only as concomitants to the distress reactions implicit in the very definition of noise, but also through reflex stimulation of auditory nerves and on the hypothalmic-hypophysical system. Exposure to noise can, therefore, cause a number of mental, as well as physical, diseases. [7]

In epidemiological studies several authors report an increased incidence of hypertension in workers exposed to high noise levels. This increase in morbidity manifests itself after eight years of exposure, reaching a maximum after 13 years of exposure. There is also an increased incidence of *nervous* complaints in similar situations. Living in areas close to a noisy airport was accompanied by increased numbers of admissions to psychiatric hospitals, according to one study. [6]

Mice, when innoculated with infectious agents in conjunction with noise stress, were more susceptible than mice just innoculated with the infectious agent alone (stromatile virus). Similarly, people who breathe pollutants (e.g., NO_x) are more prone to become ill from biological systems (e.g., Klebsiella) than from the same dose of Klebsiella without NO_x. [8]

What I am trying to point out again is that we have to look at man in his total environment. Noise by itself may be at a level which does not interfere with a person's well-being. NO_x may be at such levels that it has no measurable effect, the same with an infectious agent. But, when man is exposed to the multitude of potentially noxious stimuli, the effect may be both additive and debilitating.

So while we have been busy setting ambient air standards for such pollutants as NO_x, CO, etc., and for metals and organic compounds in water, man's defense mechanisms have been fighting insults from a multitude of sources and types, which we are now beginning to consider in our research efforts.

As we heard from several speakers we must begin to look at the complicating considerations of synergistic additive and antagonistic actions. It is important that we stress this aspect of our work. Within this concept we also have to consider these actions from several points, whether we are talking about chemical actions or intermedia actions (e.g., noise vs. chemicals, noise/radiation/chemicals). Because, unless we look at the total complement of what is present in man (or to what he is exposed), we may possibly do more harm than good by removing one component from his environment unless we can remove all unwanted stresses.

Up to now I have cited some examples of fairly easy variables to measure and quantify. But there are other things associated with living in this stressful environment which are not so easy to quantify. I am referring to subtle and sometimes not so subtle behavioral effects. I am referring to the psychophysiological effects and metabolic effects in populations residing in communities where the physical and chemical pollutants are high.

Why is it, for example, that normal rational people when sitting in a traffic jam become irrational and lose their tempers and start to fight at the slightest provocation? They have been exposed repeatedly to the stress of the work situation, the lights, the noise, the irritation of delay, the pollution from the automobiles, and possibly from the food eaten, and other factors. We had better start to look at this complex problem in a coordinated and accelerated fashion.

Why do we see increases in incidences of headaches in our population? [9] Is it because of physical stressors like light and noise, or from noxious gases we breathe, or is the cause to be found in a combination of these environmental stressors? Will the removal of the noxious gases we breathe be enough to alleviate the headaches without also doing something about the flickering lights or the noises? By removing the noxious gases from the air, will we alleviate the suffering from increasing frequency of attacks in asthma patients or do we also have to remove the psychological stressors?

We know that life changes act as stressors (provoking "stress selye"), thereby increasing the wear and tear in the organism and eventually leading to a rise in morbidity and mortality. The casual relationships between exposure to psychosocial stressors such as crowding, unemployment, malnutrition, and subsequent disease is supported by numerous studies [6,10,11].

The general concept of psychosocially mediated ill health is that a wide range of environmental situations (such as those related to population density and migration) may engage a relatively small number of pathogenic physiological mechanisms, which may lead to precursors of a large variety of diseases and eventually to the diseases themselves. These are factors which I have not yet elaborated on but which we must consider. Because as we consider the quality of life we must take into account the totality of all components concerned, balancing against each other the various needs of the individual and the politically determined priorities concerning the needs of various individuals and groups. The EPA has begun to look at this, but the effort is small compared to what is needed. Maybe this is an area of future collaboration.

I hope I have made my point regarding the need for looking at the total environment but let me add another regarding this mobile population we have today.

Certain chronic diseases have been associated with migration status. As summarized by Myers [11], the evidence on coronary heart disease indicates higher rates for rural people migrating to the city than for native urbanites in the U.S. cities studied. This could be attributed to the new physical, chemical, and psychological stress imposed on the migrant.

Haenzel, et al. [12,13] found the mortality from lung cancer higher among urban residents born in rural areas than in lifetime residents (with age and level of smoking controlled). The cause could again be due to the physical and chemical stresses, it could also mean that born urbanites have adjusted, adapted, or compensated (increased tolerance) to the stressful environment. But, we don't know for sure, do we? Also, Korpi [14] compared the number of days on sick leave. Male migrants from rural areas were found to exhibit higher absenteeism than persons born in cities. The more urbanized the area to which they migrated, the higher the absenteeism. Females exhibited similar trends.

I realize, as you do, that the whole picture of environmental stressors as it impacts on man is complex and that we have to begin to look at something. So we look at air pollutants and their effects and water pollutants and their effects. A piecemeal effort to be sure, but a start.

But as we do this, why can't we also start to put the pieces together in a coordinated fashion? There is enough for all the U.S. agencies to do and there is enough for the Soviet agencies to do without overlapping on each other's work.

So my plea is this:

Why not start to look at man as an entity, look at what he is exposed to outdoors, indoors, in the workplace, and what he eats. Sure, we can start by looking at individual pollutants as man must handle them, whether it is asbestos from air, water, food, or dermal contact. At least then we are looking at the total body burden of asbestos. We can do the same for specific organic compounds or anything else.

At the same time, someone else can look at the effects of electromagnetic radiation (e.g., radar) which is suspected of causing cancer, cardiovascular changes, and even birth defects in people living in the vicinity of areas with radar usage and of altering immunological response.

We also need a centralized authority who can oversee what all the various agencies are doing and that they are doing it in a coordinated and collaborative fashion. This would make sense, at least to me, both scientifically and economically.

We can start to screen out dangerous chemical compounds before they are used in products or manufacturing processes. This would diminish new toxic substances from entering the environment. This, however, is easier said than done. (Some 2 million chemical compounds are known, and an estimated 25,000 new ones are developed every year. Of this total, about 10,000 have significant commercial use, and most of them are not dangerous. Even so, to test those that might be carcinogens, cause birth defects and other diseases would be time-consuming and costly [15].) It can, however, be done, by close cooperation between manufacturers and government, in a check and balance of testing and regulatory functions. There could also be a mandatory heavy fine; e.g., $100,000 per day for noncooperation or violations, or closing of the manufacturing plant until pollution has been reduced to acceptable levels.

I would also convene a national task force of experts who would develop the overall strategy and set the priority for the various projects. This could later be expanded to encompass an international body of experts under the auspices of the U.N. or WHO, but new mandates and authorities would be needed for that. [16]

On the international level, since environmental stress is universal, closer collaborations and exchange of informaion among all nations make equally as much sense and for the same scientific and economic reasons.

Above all else, agreement between the nations on definitions (criteria) and methods of measurement of pollution is obviously desirable if the results of research work in different countries are to be compared.

For example, if we look at the NO_x standards, we find for:

United States	0.05 ppm/year, 0.13 ppm/24 hours
Canada	0.10 ppm/24 hours, 0.20 ppm/hour
West Germany	0.05 ppm/long term, 0.15 ppm/short term
Japan	0.02 ppm/24 hours
USSR	0.05 ppm/24 hours

Why these differences in standards when the human body is affected the same way, regardless of nationality? We live on this planet together, and together we have to take care of it. It is not very big, is it?

Thank you for letting me give you my philosophy on the problems of environmental stress as I see them facing man.

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INTERNAL SUBSTANCE CYCLING IN THE MAIN TYPES OF THE NATURAL ECOSYSTEMS OVER THE TERRITORY

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Development of regional-geographic or ecological investigations and the multiplicity of approaches employed leads not only to a rapid accumulation of a variety of data on natural ecosystems, but also poses many new tasks in the fields of geography and biology. Included among such problems is the paramount one of the typology of natural ecosystems as one of the cornerstones in the building of their general classification.

Generally speaking, a complete scientific typology of natural ecosystems (regions) still does not exist, although there are numerous approaches to it, primarily based on the classification of descriptive material of a geographic (geobotanical, soil-geographic and physico-geographic) nature. The general result of the processing of such materials led to the definition of the main types of existing natural ecosystems as well as their physiognomic characteristics. Currently these characteristics are being updated with data characterizing the conditions of the environment (for example, climatological, hydrological and others) and the levels of the biological productivity of various natural ecosystems which assigns to them a certain quantitative definiteness. However, this is not sufficient for the further development of the ecosystem typology.

A comprehensive typology of natural ecosystems must, in addition to its descriptive framework, proceed above all from the functional characteristics of the internal processes and the internal circulation of substances taking place in the ecosystems. In studying these processes, many complex tasks arise of course which require that extensive experimental observations be carried out. Many steps have already been taken in this direction. Nevertheless, one should not overestimate the importance of these data. Thus, for example, data on the total biomass of various ecosystems and their productivity as well as the biomass of individual components provide in themselves still insufficiently defined characteristics for the internal circulation of substances taking place in the ecosystems. As a rule, correct assessment requires additional functional (genetic) analysis of the various components' role in this evolution of the ecosystem.

At the present time there is a strong need for the most rapid development of the typology of the main natural ecosystems, using available indices from the internal circulation of substances and the functional role in it of the basic components. Such a necessity is the result of the vast scale of the intense man-made transformation of natural ecosystems, the radical disturbance of the natural internal circulation of substances and the varied and frequently ruinous consequences of it all. Therefore, one of the primary tasks of science at the present time is the possibly more reliable forecasting of the consequences of actions by man. This in turn requires a clear understanding of the essence of the basic processes and most importantly the natural circulation of substances taking place in various natural ecosystems. Moreover, the large gaps in present day scientific knowledge of such circulation have to be filled in, using a variety of hypotheses and working concepts requiring empirical verification and further clarification. The test of such an effort is presented below in the form of a number of principal conditions.

1. One of the most important indices of the general nature of the internal circulation of substances occurring in natural ecosystems is its *type*. According to this indicator all natural ecosystems can be divided into three main groups: autonomous (independent), transonomic (dependent) and subonomic (subordinate) ecosystems. Such a division despite the new terminology is sufficiently traditional. It corresponds to both the most general physico-geographic and biogeochemical systems. Thus, the *autonomous* (or independent) ecosystems should be identified, in our opinion, *with the zonal plakornymi* [?] or water divide formations; *transonomic* (or dependent) ecosystems with *introzonal* formations on depressions, developed along transit flows of matter, and the *subonomic* (or subordinate) ecosystems with *azonal* cumulative formations in depressions or regions of the final flow of the matter, removed from the autonomous systems. The above-cited comparison makes it unnecessary to comment further on the discussion which attempts to link various types of the circulation of substances in the ecosystems with

the use of the substances formed *in situ* as a result of erosion and soil-formation (autonomous or independent ecosystems); depending on the selective intake of substances in transitory migratory flows (transonomic or dependent ecosystems), or finally subordinated (frequently forced) to the use (accumulation) of substances from the final accumulation results (subonomic or subordinate ecosystems). It should only be stipulated that further texts will be devoted to the first group of natural ecosystems alone, that is, the autonomous systems.

2. *Autonomous* (independent) natural ecosystems in their optimum development represent formations found in a state of mobile equilibrium with the environment, that is, attaining a climax. Such a state is the result of a lengthy evolution (within the framework of geological time) for each type of the autonomous ecosystem. Despite the equilibrium state, that is, the apparent stability, it at the same time does not at all signify that the autonomous ecosystems, having attained the present level of development, have ceased their further evolution. As a result of the various states of the medium in which such ecosystems exist as well as a result of the defined composition of their biota predetermined by the entire course of preceding evolutionary development, they possess *a distinct degree of being locked in*, that is, independence of their circulation of substances. A specific level of being enclosed, that is, the ability to most fully utilize the substances entering the ecosystem without loss (return within) or excessive accumulation in its limits in the form of an inert, unusable product may serve as an important index of the overall perfection of the internal organization of the autonomous ecosystem. As will be demonstrated below, different types of natural ecosystems are characterized by various levels (degrees) of their being closed in, that is, basic differences in the levels of their organization.

3. Along with the different degrees of locking in the circulation of the substances, the autonomous natural ecosystems can be characterized as well by other integral and differentiated indices of the internal circulation of substances. Let us select from among them, first of all, *the intensity or rate of the circulation of the substances*, which we can judge by the relationship of the entire mass of the *annual biological production of the specific ecosystem to its total biomass*. Apparently, the smaller the value, the greater in that ecosystem is the delay of the substances in the circulation and even their temporary conservation in a specific form. On the contrary, an increase of the specific indicator points to a more rapid or intensive circulation of substances, peculiar to that ecosystem, that is, its greater dynamism. It should be noted that this integral index of the intensity of the internal processes of the circulation of the substances in the ecosystems can and must be supplemented with additional differential indices such as the relationship of the annual increase in the growth of the flora and the total increase of the phytomass, the relationship of the scope of the annual decrease in the flora to the reserves of the cover, and others. A comparison of such differential indices of the intensity of the circulation of substances with each other as well as with the integral indices provides important and specific definitions for the various types of the ecosystem.

4. An important general index of the internal processes in the ecosystems is *the structure of the circulation of the substances*. It can be judged on the basis of various peculiarities of the ecosystem and various indices. Let us single out three of the most general which may be defined as the most accomplished, balanced and residual productivity of the circulation of substances in the ecosystem.

—The first of these, that is, *the most accomplished* may be characterized by the degree of utilization of its entire organic mass, created in the ecosystem through its own effort. Obviously the most important portion of the expenditure of the organic substance in any ecosystem in the process of its functioning is the use of its breathing for the entire biota comprising the ecosystem. Therefore, the most integrated measure of perfection of the overall structure of the circulation is the degree of utilization of the *annual increase* of the biomass on the breathing of the living organisms — plants and animals comprising the ecosystem. In ecosystem-climaxes in a state of dynamic equilibrium with the environment, such a measure must be equal, that is, 100% (zero). If, however, the ecosystem produces a somewhat greater biomass than is necessary for breathing its own biomass, then the structure of the internal circulation of the substance becomes incomplete. Apparently, this is a property which is temporary for succeeding ecosystems which have not reached climax equilibrium.

—The second characteristic of the structure of the circulation of substances in the ecosystems has been named by us as the degree of *balance*. It can be judged in the most integrated form by the relationship of the *primary and secondary biological* production in the ecosystem. The high significance of this index always points to the presence in the ecosystem of primary material which is used sparingly or not at all in the course of the subsequent circulation of substances, while the lower values speak of a more effective structure of the circulation in the ecosystem as a result of the attained symmetry in the rate of production of the primary product and the rate of its further consumption and transformation.

Apparently, this indicator again points to the general level of organization of the particular ecosystem.

—Finally, the *residual productivity* of the internal circulation of substances may be defined as the general relationship of the *mass of the living biota* with the dead organic matter accumulated in the makeup of the ecosystem. Such dead organic matter may serve as an unnecessary ballast in the ecosystem with little or no value.

Such an example is peat in an automorphic swamp. However, in many other instances, dead organic matter, created and accumulated within the ecosystem may be an extremely important reserve of nutritive and other substances necessary to the ecosystem. This reserve, as it were, temporarily removed from the internal circulation, is used by the ecosystem only periodically in crisis situations for the existence of the ecosystem. It is specifically for this reason that it plays the role of an insurance policy for the self-preservation of the ecosystem. An example of such a reserve is the dead forest underbrush or the reserves of humus in the soil.

5. There is no doubt, that many other indices, both integral and differential, may be used to characterize the internal circulation of the substances taking place in the autonomous natural ecosystems (as well as in the dependent and subordinant ecosystems) and the most important functions of their components. However, the task of examining all such indices goes beyond the framework of this paper. Therefore, below we shall employ, to characterize the main types of zonal ecosystems, peculiar to the USSR, only a limited system of the above-mentioned indices supplemented for explanatory purposes with certain other qualitative characteristics.

6. The tundra ecosystems exist under conditions of a significant shortage of heat and relatively good moisture. As a result of the brevity of a warm period during the year and particularly as a result of the low temperatures of the soil and its permanent gley soil (tundra gley soil) its phytomass is negligible. The annual phytomass production is also small, particularly that of the land mass. As a result the *intensity* of the circulation of the substances here is small, the *structure* is characterized by noticeable residual accumulation as a result of which the initial production is regularly underutilized and in the upper layers of most of the soil there is an accumulation of undecomposed vegetative residue—the formation of peat pointing to the irrevocable loss of a significant quantity of organic matter and with it of biogens from biological circulation. This, apparently, points to the insufficient evolution of tundra ecosystems which perhaps is explained by the absolute geological youth of the tundra ecosystems appearing on the surface of the Earth only during the Pleistocene (second half) and formed from as yet insufficiently adapted biota components.

7. Ecosystems of tayga dark-coniferous forests. Despite the vast overall phytomass, formed primarily by the wood and perennial reserve of conifers, the annual increase of the flora here is relatively small. The total zoomass in the dark-coniferous forests as a rule, is also small and is represented primarily by saprophage which together with bacteria and fungus take part in the conversion of the vegetation remains on the surface of the soil and in its upper layers. Here the acid decay products are formed and act on the mineral soil mass, stimulating its decomposition (podzol formation). As a result of the shadiness of the forests and cold soil the destruction of the flora-detrite takes place slowly while the podzol soils possess a low absorption capability, the plants in turn do not ripen and cannot fully employ the mineral products of the organic decay. As a result many substances, including biogens, are washed out in the form of organo-mineral compounds in sub-soil horizons reaching subsurface water and thereby are lost to the ecosystems. The low *intensity* circulation of substances and their unfavorable *structure* (vast accumulation of wood), as well as the large losses of substances under the autonomous conditions also point to the insufficient evolutionary perfection which is possibly linked to the absolute geological youth of the tayga systems on the plains of the USSR, located there as a result of the broad expansion still relatively recently. Perhaps, therefore, under the natural conditions of the tayga ecosystem there are tendencies simply to degenerate or be replaced by other, although temporary, ecosystems, for example, low-leaved forests.

8. Ecosystems of defoliated broad-leafed forests possess a large phytomass in comparison with the dark coniferous forests. They also differ by a much greater production of green matter. The total zoomass in these forests reaches great values. Animals use with great intensity and over many months of the year the primary production, in part the green form, and primarily that shed by the trees and together with richly represented bacteria and fungus successfully reduce the substances, synthesized by the plants, to mineralization. Gray and brown forest soil is formed here rich in clay minerals. As a result of their large quantity in the soil, the biogens are retained easily and in large volume in the absorption complex of the soils and are used again by the roots of plants, thereby not leaving the internal circulation of the entire ecosystem. As a result the circulation of substances in the broad-leafed forests is, to a significant degree, closed as demonstrated by the poor development of podzol formation although in places and particularly in areas with a more humid

climate it is seen (in acidic brown forest soils). Normally, however, the gray and particularly the brown forest soils of broad-leafed forests contain a significant reserve of nutritive substances used not only by adult trees but also by brush, underbrush and grasses.

9. *Ecosystems of the meadow steppe* are characterized by a smaller overall phytomass; however, the increase in them of the green mass is almost the same as for the broad-leafed forests while the general increase of the phytomass frequently even exceeds it. The zoomass is sizeable with the animals intensely using the green parts of the plants, their roots and detritus. By the formation of fertile chernozen, the soil layer of the described ecosystems accumulates a vast reserve of nutritive matter. These substances stored over a long period of time in a thick humus layer of the chernozen in time enter the biological circulation through the plant with deep root systems as a result of the burrowing activity of rodents, primarily of badgers and gophers. The presence of so large a reserve of biogens although it reduces the intensity of the overall circulation of substances is an important condition for imparting general stability to the characterized ecosystems capable of withstanding extreme conditions of periodic crises (above all drought) in the external environment.

10. The functional structure of the ecosystems of *arid steppes* is basically comparable to that of the meadow steppe, but the total phytomass and its annual production are less in this case; the green parts of the plants and the roots are used more intensely by the animals; mineralization of organisms takes place more fully. Small quantities of precipitation, dry air and dry upper layers of the soil decrease the vitality of the plants that during the intense treatment of the biological production, leads to an excess accumulation of mineral compounds in the soil, with which the significant soil alkalinity (chestnut soils and alkaline complexes) is linked.

11. *Arid natural ecosystems* on the territory of the USSR are very diverse, but some general features are common in the desert zone to the psammaphytic or clay-less ecosystems. With a relatively small total phytomass and low production of the green mass in these ecosystems, the significant share of the phytomass is composed of hardwood plant fibre — surface and subsurface organs. Animals, particularly in the southern desert belt, demonstrate substantial activity throughout the year, vary in their relationship to the systematic composition and adaptation, and have a relatively large zoomass. Therefore, the desert animals, very quickly and even greedily consume the primary small phytoproduction and together with the bacteria provide its nearly total mineralization. As a result the desert soils contain little humus, but are rich in biogens. The latter, as a result of a shortage of moisture, cannot always be quickly used by the plants, which, just as the dryness of the climate, promotes the accumulation in the soils of large reserves of substances, up to the extreme leading to their salinization (brown and grey-brown desert soils).

12. The review of the surface autonomous natural ecosystems shows that *the high degree of the closed circulation of substances is characteristic of the majority of zonal ecosystems* in the USSR, including those which are most productive. Clearly an incomplete circulation with a large loss of biogens is peculiar to the ecosystems of the tundra and the dark coniferous forests of the tayga. The rate of circulation of substances as a whole is the greatest for the ecosystems of the broad-leafed forests and grassy ecosystems of the semi-arid areas where the favorable combination of heat and moisture provide the diversity and high vitality of the plants, animals and bacteria, and the speed of synthesizing the primary product and transformation into the secondary. Moreover, there is an important and basic difference between these two types of natural ecosystems in regard to the reserve of biogenic substances. This reserve is small for the broad-leafed forests and great in the steppe which is of vast significance for providing the latter with a high degree of stability in crisis situations in the external environment (primarily droughts). Desert natural ecosystems of an autonomous nature are also marked by varied distinctions in the internal organization.

13. Man-made changes of natural ecosystems, have to a greater or lesser degree occurred throughout the USSR. in some instances the natural ecosystems have basically retained their natural characteristics, while in others they have changed completely and were replaced by the man-made. Simultaneously, the man-made changes in the natural ecosystems and their replacement by secondary ones, excessively exploited for agricultural purposes, first of all are the result of a basic transformation of the plant cover during the planting of agricultural crops, the extensive use of pastures and hay cutting for feeding farm animals, and with the cutting of trees or their intensive exploitation. It is natural that with all of these forms of actions by man, the internal circulation of substances in the natural ecosystems is subjected to varied transformation.

Thus, in the *tundra and in a majority of tayga territories* even with extensive man-made changes of the natural ecosystems the biological circulation of substances intensifies somewhat, the plant cover and the animal population increase and the biological productivity of the territory as a whole increases.

In the area of the spread of coniferous-broad-leafed and broad-leafed forests an original forest-pasture-field complex of man-made ecosystems was formed as the result of the transformation of natural ecosystems, as a rule with significant biological productivity and a number of other features of its internal circulation of substances.

Conversely, in the forest-steppes and steppes, that is, in the particularly productive natural ecosystems, the nearly total ploughing of land led to the depletion of the composition of the vegetative and animal population, and to a disturbance of the natural processes of the circulation of substances. Therefore, the soils in the ecosystems under study, began with the extensive utilization, to lose the reserve of biogens accumulated over the centuries, as a result both of the depletion of land animal population and the constant exclusion of a large quantity of the mass produced by the plants from the agricultural-cattle ecosystems. However, under the conditions of intense farming all of this was neutralized by the introduction of fertilizer into the soil, an improvement in the level of agrotechnology and the rational methods of crop rotation. Planted, highly productive ecosystems which appeared as a result of meadow steppes show the formation of many new features in the course of the internal processes and above all in the nature of the internal circulation. Extensive cattle breeding in the arid steppes also leads to the depletion of the natural ecosystems and a drop in their natural biological productivity, while on the irrigated territories of the desert the total biological productivity and primary production increase significantly. On the basis of natural ecosystems new types of oasis ecosystems are also formed here.

14. Generally it may be stated that the *man-made ecosystems* characterized by a permanent depletion of substances, including biogens, in the form of agricultural products, cease to be autonomous ecosystems and in essence become dependent on man, requiring for the maintenance of the natural productivity, and even more so for its growth, appropriate compensation in the form of rich fertilizer and other measures.

The replacement of the natural ecosystems with the man-made resulted in many other consequences. Thus, for example, the destruction of a living cover highly adapted to local conditions frequently leads to the intensive development of water and wind erosion accompanied by the loss of substances needed by the plants, beyond the limits of the ecosystem a disturbance of the water system of the territory, soil degradation, and so forth.

It follows that man, keeping in mind the need for prolonged use and maintenance of high productivity both of natural as well as the creation of man-made systems, must take it upon himself to carry out specific ecological functions. This must, however, be based on a comprehensive knowledge of the entire dynamic of natural ecosystems, their internal circulation of substances as well as the laws governing the transformation of natural ecosystems into man-made ecosystems. This points to the necessity for an all out effort in studying the physical, chemical, and biological phenomena taking place in the geographical landscapes, primarily aimed at a study of the relationship of the environment and biota in the ecosystems as well as the internal circulation of substances in various types of natural and man-made ecosystems.

GLOBAL BALANCE AND MAXIMUM PERMISSIBLE MERCURY EMISSIONS INTO THE ATMOSPHERE

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and A. KH. OSTROMOGIL'SKIY

INTRODUCTION

This paper, using mercury as an example, shows that limitations for man-made emissions into the environment may arise not as a result of the pollution of those surroundings into which they are directly emitted, but as a result of the processes of secondary pollution of other surroundings. In particular, for mercury, when there are atmospheric emissions, dangerous situations arise first of all as a result of the pollution of small bodies of water along the chain, air-land-water. The effects of this type should be carefully studied and considered when establishing standards both for the extent of the concentration and the extent of the emissions themselves.

Mercury compounds are among the most toxic pollutants of the environment. Their accumulation in the biosphere is caused by different types of human economic activity. The majority of man-made mercury enters the atmosphere as a result of the burning of coal, oil and municipal garbage, as well as the activity of enterprises of the chemical industry [1,2].

Until now it was believed that the mercury entering the atmosphere, given the natural processes and the emissions of industries, had the same life span (residence) in the atmosphere. Along these lines, a materials-balance analysis of mercury was constructed, and the dynamics of the possible pollution of the biosphere were appraised [1,2]. Serious grounds have forced us to doubt the correctness of this suggestion. In fact, the great concentration of aerosol particles, the high chemical activity of a substance, the increased temperature in the combustion of enterprises are creating the conditions for the existence of mercury vapors, which differ significantly from the conditions in the clear atmosphere. A significant portion of the aerosols being emitted in combustion, by which mercury vapors are being derived from the atmosphere, have a life span that is shorter than natural atmospheric aerosols.

In this work on the varying life span (residence) in the atmosphere of mercury of natural and man-made origin, the existing patterns of the global balance of mercury were modified. Here we present an analysis of the modified model, of the results of experimental determination and substantiation of the parameters of the model, and an evaluation of the effects of the pollution of the biosphere.

In creating the model, the goal was pursued to obtain a simple calculating scheme that contains the most important properties of the global cycle of mercury and, at the same time, includes only those parameters, the order of magnitude of which is either known with sufficient reliability, or can be determined experimentally. It seems that such an approach in a certain sense is more fruitful than the calculation of numerous connections without the possibility of giving the appropriate quantitative evaluations for their description. In this case, by this method, we succeeded in obtaining evaluations of the effects of pollution which arise because of the different behavior of natural and anthropogenic mercury. The additional calculation of the local effects made it possible to evaluate the permissible emissions of man-made mercury into the atmosphere.

DESCRIPTION OF THE MODEL

The model examines two types of sources of the entrance of mercury into the biosphere: natural — q_{nat} into the soil and man-made — q_{ant} into the atmosphere. Natural mercury enters as a result of the processes of weathering when there is a break-up of the crystal lattice of minerals of rocks and soils. Man-made mercury enters the atmosphere as a result of its direct emission, see Figure 1.

Mercury circulates between the atmosphere and the lithosphere and is taken out of circulation only as a result of passage into the hydrosphere. The fate of mercury in the hydrosphere is not examined; we believe that its passage from the hydrosphere into the atmosphere and soil within the examined time intervals (on the order of hundreds of years) may be omitted. Therefore, the model does not examine direct emissions of man-made mercury into the hydrosphere. The model omits a number of secondary sources, such as volcanoes, owing to their low intensity [1,2].

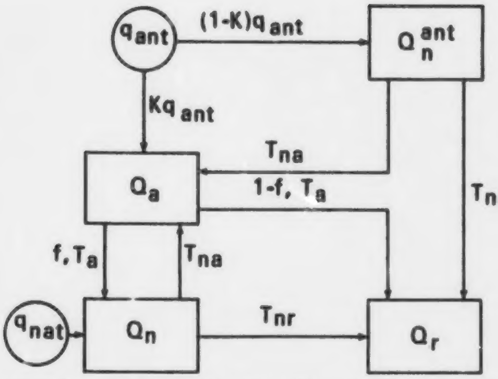

Figure 1. Scheme of the circulation of mercury in the atmosphere-lithosphere-hydrosphere system.

The mercury in the coarse-dispersed fractions of emissions of enterprises falls near the enterprises. Its amount is equal to $(1-K)q_{ant}$, its time span in the atmosphere is accepted as being equal to zero (in practice it is measurable in hours). Mercury vapors precipitated in the fine-dispersed fraction or having left the flame, will be dispersed just like natural mercury with a life span in the atmosphere of τ_a. The amount of this mercury, which is equal to q_{ant}, in the emissions of enterprises is determined by the equipment and increases with the removal of aerosols from the emissions.

The time for mercury to move from the soil into the atmosphere τ_{na} is accepted as being equal for man-made and natural mercury, and the time to move from the soil into the hydrosphere, τ_{nr}, is also considered identical.

Let us introduce the following designations for variables:

—Q_a is the background amount of mercury in the atmosphere (not including local pollution near enterprises);

—Q_n is the amount of mercury in soils, which participates in global circulation;

—Q_n^{ant} is the amount of anthropogenic mercury in the soil near enterprises;

—Q_r is the amount of mercury that has entered the hydrosphere only through processes in the system atmosphere-soil without consideration of other means.

Let us keep in mind that only a part of the background atmosphhheric mercury, which is equal to fQ_a, falls onto dry land. For man-made mercury that falls near enterprises, it can be considered that it falls on dry land. In these assumptions we will have the following system of differential equations which describes the global balance of mercury:

$$\frac{dQ_a}{dt} = kq_{ant} - \frac{Q_a}{\tau_a} - \frac{Q_n + Q_n^{ant}}{\tau_{na}} ;$$

$$\frac{dQ_n}{dt} = f\frac{Q_a}{\tau_a} + q_{na} - \frac{Q_n}{\tau_{na}} - \frac{Q_n}{\tau_{nr}} ; \qquad (1)$$

$$\frac{dQ_n^{ant}}{dt} = (1-k)q_{ant} - \frac{Q_n^{ant}}{\tau_{na}} - \frac{Q_n^{ant}}{\tau_{nr}} .$$

RESULTS OF THE EXPERIMENTS AND THEIR ANALYSIS

The main task of the experimental verification of the model was the establishment of the difference in the behavior of natural and man-made mercury in the atmosphere and the evaluation of the amount of mercury in the atmosphere Q_a. With this purpose in mind, airplane studies of the background levels of the concentrations of mercury vapors were conducted over the European part of the USSR and Central Asia. The measurements were made at great distances from man-made sources of mercury, in order to avoid the influence of local pollution of the atmosphere. In addition to the measurement of background concentration, measurements were made of the emission of mercury vapors by man-made sources.

The measurements were made with an atomic-adsorption gas analyzer [3,4], the sensitivity of which in the airplane variant, owing to the injection of large volumes of air, was reduced to 10^{-11} g/m. In order to obtain additional information, parallel measurement was made of the concentration of the short-lived products of the decomposition of radon. Considerable attention was devoted to the study of the high-altitude distribution of mercury vapors in the atmosphere, which is necessary for an evaluation of the background content of mercury in the atmosphere. The combined data on the high-altitude dependence of mercury vapors and short-lived products of the decomposition of radon, the source of which are soil and rock in the atmosphere, served as the basis for determining the life span of mercury vapors in the atmosphere.

In different regions of the USSR, 11 high-altitude probes in the atmosphere at altitude ranges of 50 to 4000 m were made. The probe was made under different meteorological conditions. A characteristic feature of all these measurements was the fact that the profiles of the high-altitude curves for mercury vapors and the short-lived products of the decomposition of radon, which are in a state of equilibrium with them, practically coincide. One of the diagrams of the high-altitude dependence for mercury vapors and the products of the decomposition of radon is cited in Figure 2. The satisfactory coincidence of the high-altitude distribution of concentrations indicates, first of all, that the source of mercury vapors in the atmosphere, just as that of radon, is the earth's surface, and the direct contribution of local anthropo-

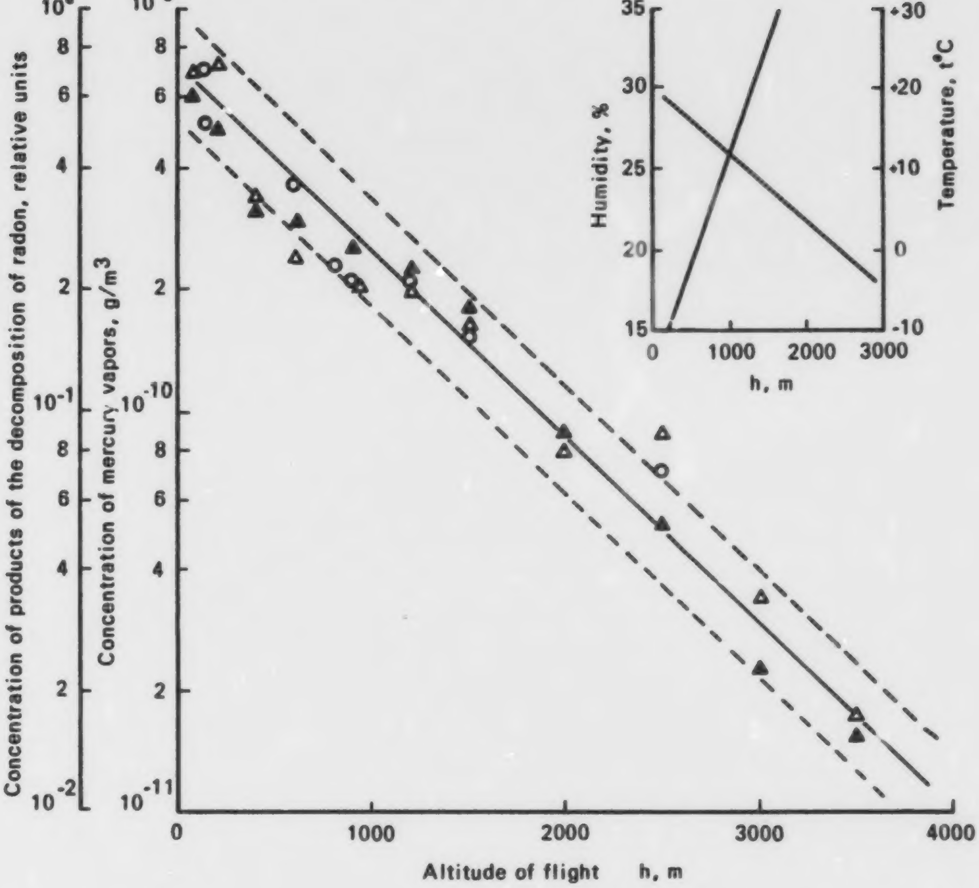

Figure 2. The altitude dependence of the concentration in the atmosphere of mercury vapors ——; of the products of the decomposition of radon ——! of mercury vapors, measured simultaneously with the products of the decomposition of radon ——.

genic sources is negligibly small. Secondly, this means that the life span of mercury vapors coincides with the life span of radon (we will return to this question below). Regardless of the form of high-altitude dependence, the concentrations of mercury at altitudes around 3000 m became very small, practically equal to zero. The amount of mercury in the air column from 50 to 4000 m, in the same region with a change in the form of the high-altitude curve depending on the meteorological conditions, changed relatively slightly within the limits of 20 to 30%.

In the altitude range of 0 to 50 m, the altitude distribution of mercury vapors was not studied. At the earth's surface, one can observe an increase in the concentration of mercury vapors [5], but this does not affect its total amount in the atmospheric column.

In order to evaluate the background content of mercury in the atmosphere, apart from the altitude distribution of mercury, one must know the spatial variations of the concentration of mercury on the earth's surface. Such measurements were made on a sufficiently extensive and representative part of the territory of the USSR. In Table 1, the average concentrations of mercury vapors C for the different regions are cited for an altitude of 50 m above ground level. The measurements were made during the warm part of the year, when there was no snow cover and under the conditions of intensive atmospheric agitation. Table 1 also indicates the coefficient of variation, calculated according to the results of a number of measurements made during flight over regions that are relatively identical in geological and soil conditions.

TABLE 1. AVERAGE CONTENT OF MERCURY VAPORS C IN THE ATMOSPHERE AT A LEVEL OF 50 m FROM THE EARTH'S SURFACE

No.	Region and geological soil conditions	10^{-9}g/m^3, error, %	Coefficient of variation, %
1.	Moscow oblast. Moscow area basin. Carboniferous system. Soddy podzolic soils.	0.60 (7%)	15
2.	Vitebskaya oblast. Orshinskiy depression. Devonian system. Soddy podzolic soils.	0.60 (7%)	15
3.	Zhdanovskaya Oblast. Ukrainian shield. Micellar calcareous black earths.	1.0 (5%)	15
4.	Kishinevskaya oblast. Declivity of Ukrainian crystal massif. Neogene system. Podsolized and typical black earths.	1.0 (10%)	20
5.	Pensenskaya and Saratovskaya oblasts. Volgo-Ural anteclise. Cretaceous and Neogene deposits. Black earths.	0.84 (16%)	30
6.	Saratovskaya and northern Volgogradskaya oblasts. Volgo-Ural anteclise. Cretaceous, Neogene and Quaternary deposits. Dark chestnut soils.	0.70 (5%)	6
7.	Southern Volgogradskaya and Astrakhanskaya oblasts. Caspian region syneclise. Quaternary deposits. Brown desert-steppe solonetzic soils.	0.67 (20%)	30
8.	Kokandskaya and Namanganskaya oblasts. Tyan'-Shan' variscites. Paleozoic and Mesozoic deposits. Gray desert soils.	0.60 (10%)	15
9.	Ferganskaya and Andizhanskaya oblasts. Tyan'-Shan' variscites. Paleozoic and Mesozoic deposits. Meadow-gray desert soils.	0.75 (10%)	20
10.	Yuzhnyy Ustyurt. Zaunguzskiye Kara-Kumy. Turanskaya platform. Neogene and Quaternary deposits. Aeolian sands.	0.54 (17%)	25
11.	Severnyye Kyzyl-Kumy. Turanskaya platform. Neogene and Quaternary deposits. Aeolian sands.	0.45 (18%)	20
12.	Karshinskaya steppe. Turanskaya platform. Paleogene and Quaternary deposits. Gray-brown desert soils.	0.36 (40%)	25
13.	Khorezmskaya oblast. Turanskaya platform. Quaternary system. Meadow-gray desert soils.	0.72 (14%)	17
14.	Rabat-Chorku-Batken valley. Alayskiy chain. Silurian, Devonian and Carboniferous deposits. Mountain gray desert soils.	6.6 (45%)	70
15.	Zaravshanskiy chain. Koktash plateau. Silurian and Carboniferous deposits. Mountain-cinnamonic soils.	1.2 (50%)	100

The territory studied has various geographical-landscape zones and geochemical provinces and therefore is sufficiently representative, in global scale, for a description of the distribution of mercury above the continent.

The average concentrations of mercury vapors, for the various regions, lies within the limits (0.4 to 7)$\cdot 10^{-9}$g/m^3. The minimum concentrations fall to the regions with a massive covering of loose deposits. Concentrations on an order of $1 \cdot 10^{-9}$g/m^3 were observed only in local sectors in the region of the Turkestan-Alaysk mercury belt. On the whole, the area distribution of mercury vapors is closely connected with the concentration of mercury in soils and rocks, and is consistent with the surface measurements made in some of the regions being examined [3,4].

In order to calculate the time that the mercury remained in the atmosphere, we took advantage of the fact that the profiles of the altitude distribution of vapors of the concentration of mercury and the short-lived products of the decomposition of radon coincide when measured under different meteorological conditions. Then, by using, for example, the model of transference as a result of turbulent diffusion and considering that the rate of elimination of mercury is proportional to the magnitude of its concentration C_{Hg}, it is possible to obtain that:

$$\frac{\delta}{\delta z}\left(Kz\,\frac{C_{Hg}}{\delta z}\right) - \frac{C_{Hg}}{\tau_{vap}} = 0; \qquad (2)$$

$$C_{Hg}\Big|_{z=0} = Co; \; C_{Hg}\Big|_{z=\infty} = 0,$$

where K_z is the coefficient of turbulent agitation, generally speaking, which depends on the altitude and τ_{vap} is the life span of the mercury vapors in the atmosphere.

Equations (2) will also describe the altitude distribution in the atmosphere of concentration of radon C_{rad} with a life span of $\tau_{rad} \approx 5.5$ days, which is determined only by radioactive decomposition. The coincidence of the profiles of the altitude distribution of mercury and radon, which is observed in different situations, means that the functions C_{Hg} and C_{rad} are linearly dependent, which is not difficult to show, is correct only under the condition

$$\tau_{vap} = \tau_{rad}. \qquad (3)$$

Condition equation (3) is independent not only of the specific value of the coefficient of the turbulent agitation K_z in equation (2), but even of the adopted model. It is important only that the model being used is linear with respect to the concentration (C_{Hg}). Therefore, we believe that it has been experimentally proven that $\tau_{vap} \simeq 5$ days.

According to existing notions the basic mechanism for the elimination of mercury vapors from the atmosphere is their deposition on aerosol particles, possibly with the simultaneous occurrence in a number of cases of chemical reactions, with the subsequent precipitation of the aerosol particles. Thus, given the established equilibrium between the vapor and aerosol phases, the life span of mercury τ_a is equal to

$$\tau_a = \tau_{vap} + \tau_{aer} \qquad (4)$$

and

$$\frac{\tau_{vap}}{\tau_{aer}} = \frac{C_{vap}}{C_{aer}} \qquad (5)$$

where C_{vap} and C_{aer} are the concentrations of mercury in the vapor and aerosol phases respectively.

Let us note that for continental areas the life span of the aerosols that capture the products of the decomposition of radon fluctuates from 1 to 40 days, and values on the order of 5 days are quite normal [6]. This likewise corresponds to existing notions, as follows from [3,4], that given the established equilibrium, the concentrations of mercury in the vapor and aerosol phases do not differ greatly [7]. Thus, the life span of mercury in the atmosphere τ_a can be calculated as $\tau_a = 10$ days. As is shown by the analysis of the data of Table 1 and the altitude distributions of mercury vapors, given that $C_{aer} \approx C_{vap}$, the average amount of mercury in the air column above continental areas is equal to 1.5 ± 0.5 g/km². This evaluation and the value we obtained for the life span of mercury in the atmosphere above continental areas are quite consistent with the available data on the precipitation of mercury for continental regions. According to [2,8] it is 0.2 ± 0.1 g/km² • day; according to our calculations it should be 0.15 g/km² • day.

Now it is possible also to calculate the amount of mercury in the atmosphere, which is contained above continental areas, ≈ 260 t. The concentrations of mercury above the ocean according to the little data we have and according to [2] are almost on an order of a magnitude less than the concentrations above dry land, see Table 2. Taking this into consideration the total amount of mercury in the atmosphere can be calculated as $Q_a \approx 350$ t. This value is approximately 30 times less than the value obtained in [2], which in our opinion is erroneous. It should be noted that, although the life span of mercury in the atmosphere above continental and ocean areas can differ, this difference should not have a strong effect on the time that the mercury remains in the atmosphere as a whole, since the concentrations of mercury above the ocean drop significantly and the total amount of mercury precipitating above the ocean is very small.

TABLE 2. CONCENTRATIONS OF MERCURY VAPORS IN THE REGION OF SEA BASINS OF THE USSR

No.	Location of measurement	Altitude of flight (m)	Concentration of Hg vapors, 10^{-10}g/m³	Weather conditions
1.	Caspian Sea (central part)	200	2.0	SE, 6m/sec, 15°C
2.	Caspian Sea (central part)	200	2.5	NNE, 5m/sec, 20°C
3.	Barents Sea (Perchorskaya Guba)	200	0.3	SSW, 5m/sec, −10°C
4.	Karsk Sea (Baydaratskaya Guba)	200	0.3	ENE, 5m/sec, −12°C
5.	Karsk Sea (Baydaratskaya Guba)	1500	1.0	NNE, 5m/sec, −10°C
6.	Karsk Sea (Obskaya Guba)	2700	0.3	WNW, 7m/sec, −15°C
7.	Karsk Sea (Pyasinskiy Zaliv)	200	0.15	ENE, 7m/sec, −8°C

The measurements of the mercury vapors in the emissions of thermal electric power stations and chemical and metallurgical industrial complexes showed that the amount of mercury vapors in the profile of the flame Q decreases with the separation r from the source by the exponential law:

$$Q = Q_0 \cdot e^{-r}/V\tau_{vap} \qquad (6)$$

where V is the average wind velocity, and τ_{vap} is the life span of mercury vapors.

The processing of the experimental measurements in the profiles of the combustion of a copper-smelting metallurgical works gave the value $\tau_{vap} \approx 30$ min. For other enterprises the life span of mercury vapors in combustion was 10 to 40 min. As was mentioned, the life span of aerosols in the emissions of enterprises is significantly higher and is a magnitude on the order of several hours. Consequently, it also determines the time for the elimination of man-made mercury from the atmosphere.

The obained experimental data confirm the need to consider in the global balance model the differences between the behavior of natural and man-made mercury, which was calculated in the system of equations (1).

DETERMINATION OF THE PARAMETERS OF THE MODEL

To determine the other parameters of the model that belong to system (1), several quite realistic suggestions were made.

—In the absence of man-made sources, system (1) would be in a state of equilibrium, i.e.,

$$\frac{Q^0_a}{\tau_a} = \frac{Q^0_n}{\tau_{na}} \;; \qquad (7)$$

$$f\,\frac{Q^0_a}{\tau_{na}} + q_{nat} = \frac{Q^0_n}{\tau_{na}} + \frac{Q^0_n}{\tau_{nr}} \;; \qquad (8)$$

where Q^0_a and Q^0_n are the background content of mercury in the atmosphere and soil respectively, in the absence of man-made sources;

—Considering that the density of man-made sources has practically no influence on the vertical distribution and concentration of mercury vapors in airplane studies, see Table 1, it was assumed that of the $3.5 \cdot 10^3$ t of mercury in the atmosphere, only 50 t were caused by man-made emissions, i.e., $Q^0_a \simeq 3 \cdot 10^3$ t. This proportion does not contradict the data on mercury pollution in glaciers. Let us indicate that according to the data of various authors the proportion of man-made mercury in the atmosphere fluctuates from 10% to 80%.

—The total amount of mercury in the soil is taken to be equal to Q^0_n. This assumption is confirmed directly by the degree of pollution of glaciers.

—The value of f was taken to be 0.8. Considered here was the nonuniform distribution of dry land, which is the source of mercury in the northern and southern hemispheres, and the complicated exchange of air masses between the hemispheres. Value calculations were also made with f = 0.6.

From equations (7) and (8) it follows that

$$q_{nat} = \frac{Q^0_n}{\tau_{nr}} + (1-f)\frac{Q^0_a}{\tau_a} \qquad (9)$$

Let us calculate the first component in (9), after which we will be able to calculate q_{nat}.

Let the entrance of mercury into some body of water occur by its precipitation from the atmosphere and runoff from a catchment basin. Then the dynamics of the content of mercury in the body of water Q_w is described by the equation:

$$\frac{dQ_w}{dt} = \frac{Q_a}{\tau_a}\, f\frac{S_a}{S_l} + \frac{S_c}{S_l}\,\frac{Q_n}{\tau_{nr}} - \frac{Q_w}{\tau_w} \qquad (10)$$

where the following designations are assumed:

—S_a is the area of the surface of the body of water;

—S_c is the area of the catchment of the body of water;

—Q_w is the amount of mercury in the body of water;

—S_l is the area of dry land ($1.7 \cdot 10^8$ km²);

—Q_w/τ_w is the discharge of mercury from the body of water.

The example of Lake Baykal was examined. Owing to its great depth it is possible to assume that the decrease in the amount of deposited mercury in the water results basically through discharge from the Angara, i.e., T_w can be assumed to equal the time for complete water exchange, i.e., $T_w = 400$ liters.

The background concentrations of mercury in Baykal are calculated to be $3 \cdot 10^{-7}$ g/liter*, consequently, considering that the volume of water in Baykal is $23 \cdot 10^3$ km³, we obtain the value of the background content of mercury in Baykal, $Q_w = 7 \cdot 10^3$ t. In the absence of man-made sources the inflow and outflow of mercury should be counterbalanced, therefore

$$\frac{Q_n}{\tau_{nr}} = \left[\frac{Q^0_w}{T_w} - \frac{Q^0_a}{\tau_a}\, f\,\frac{S_a}{S_l}\right]\frac{S_l}{S_c} \;; \qquad (11)$$

For Baykal:

$S_a = 3.1 \cdot 10^4$ km²

and $S_c = 5.6 \cdot 10^5$ km³.

Hence we obtain the value:

$$\frac{Q^0_n}{\tau_{nr}} \simeq 4.8 \cdot 10^3 \text{ t/year.}$$

Using (11) we obtain $q_{nat} = 6.8 \cdot 10^3$ t/year.

As in work [1], let us take the value of the content of mercury in the soil $Q_n = 4.2 \cdot 10^6$ t. Then it is possible from (9,14) to obtain values for τ_{nr} and τ_{na}, and namely 900 and 420 years respectively.

Let us cite several other considerations that indicate that the determined values of the model parameters do not contradict the existing notions of the processes in question.

Using our calculations, the natural entrance of mercury into the atmosphere is $Q^0_n/\tau_{na} = 10^4$ t/year.

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*The personal communication of V.A. Vetrov.

The entrance of mercury into the atmosphere as a result of the processes of weathering and evaporation from the soil is calculated in different ways — from 230 to 250 t/year [1] to $2.5 + 15 \cdot 10^4$ t/year [1]. It seems to us that a figure on the order of several tens of thousands of tons per year is too high, since, given the time we established for elimination, this amount of mercury would not successfully be eliminated from the atmosphere.

From studies on the behavior of global fallouts of radioactive elements it was established that the rate at which they are washed from the soil into catchment areas is determined by the following times of elimination [9]: for readily soluble Sr^{90}, $\tau_{sr} = 200$ years; for poorly soluble Cs^{137}, $\tau_{sr} = 1000$ years. Consequently, the order of the obtained value τ_{sr} for mercury is very consistent with these data.

Table 3 cites the values of the parameters of the model, which we will use later on.

TABLE 3. PARAMETERS OF THE MODEL

No.	Name	Designation	Accepted value
1.	Time for elimination of mercury from atmosphere	τ_a	$3 \cdot 10^{-2}$
2.	Time for elimination of mercury from soil into atmosphere	τ_{sa}	$4 \cdot 10^2$
3.	Time for elimination of mercury from soil into hydrosphere	τ_{sr}	$9 \cdot 10^2$
4.	Natural sources of mercury in soil	q_{nat}	$7 \cdot 10^3$
5.	Proportion of mercury precipitated on dry land	f	0.8
6.	Proportion of anthropogenic mercury included immediately in global circulation	K	0 and 1
7.	Content of mercury in the atmosphere in the absence of anthropogenic sources	Q_a^o	$3 \cdot 10^3$
8.	Content of mercury in the soil in the absence of anthropogenic sources	Q_s^o	$4 \cdot 10^6$

FACTORS LIMITING THE EMISSIONS OF MERCURY INTO THE ATMOSPHERE

The dynamics of environmental pollution depend heavily on the change in the capacity of the man-made source over time. Figure 3 shows, as an illustration, the curves of the accumulation of mercury in the soil and the air given

$$q_{ant}(t) = 1870 + 960 \cdot e^{0.03(t-1900)} \tag{12}$$

where the time is $1900 < t < 2000$ years.

Equation (12) was obtained by approximation of the data of work [1].

As the calculations showed, the time of detection for system (1) is 300 years for local emissions and 600 years for global emissions. At the same time,

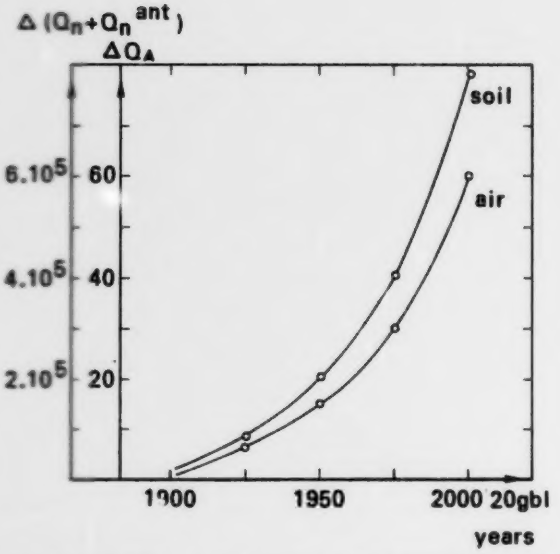

Figure 3. Dynamics of pollution of the atmosphere and soil by mercury.

the conclusions on the pollution levels, which were reached in stationary states, depend relatively weakly on the specific values of the parameters of the model and are determined mainly by the structure of the model. Considering the existing indefiniteness of the parameters of the model, this stability of conclusions from the choice of values of the parameters is quite significant.

Below is given an analysis of the pollution of the atmosphere, soils, and bodies of water in the stationary state of the system in the case of the continuous man-made entrance of mercury into the atmosphere q_{ant}.

It can be shown that in this case the following dependencies will occur:

$$\frac{\Delta Q_a}{Q_a^o} = \frac{q_{ant}}{q_{nat}}\left(1 - K\frac{\tau_{sa}}{\tau_{sr}}\right); \tag{13}$$

$$\frac{\Delta Q_s}{Q_s^o} = \frac{\Delta Q_a / Q_a^o}{1 + \tau_a q_{nat} / f\, Q_a}; \tag{14}$$

$$Q_s^{ant} = (1 - K) q_{ant}\, \tau_{sa}\, \tau_{sr} / (\tau_{sa} + \tau_{sr}) \tag{15}$$

where ΔQ_a, ΔQ_s are the excess over the background of the content of mercury through the man-made entrance in the atmosphere and soil respectively. Since the maximum permissible concentrations of mercury in the air are $3 \cdot 10^{-7}$ g/m³, from (13) it is easy to calculate that the excess of these concentrations can be achieved given an amount of anthropogenic emissions in excess of 10^4 t/year, i.e., on an order of twice as much as at present. These figures may create the illusion of a favorable situation concerning emissions of mercury into the atmosphere. However, in this case the danger of the global pollution of mercury is that, being washed from the soil, mercury pollutes natural waters and, by accumulation, can exceed the permissible concentrations.

The background content of mercury in the surface waters of dry land is about $1 \cdot 10^{-7}$ t/l. This amount is 50 times less than the maximum permissible concentration accepted in the USSR. This mercury enters as a result of being washed from the soils, i.e., given an increase in the content of mercury in the soil on the area of a catchment of 50 times, the concentration of mercury in the water will reach an impermissible amount. Such an increase in the amount of mercury on a global scale, as follows from (13) to (15), is achieved when $q_{ant} \risingdotseq (7 \div 10) \cdot 10^{4}$ t/year, which exceeds by $7 \div 10$ times the present emissions 10^{4} t/year [1,2]. This calculation shows that emissions of mercury into the atmosphere may become a very dangerous factor.

On local scales such situations may be forming even at the present. Since in the established regime the part being washed from the soils is $\tau_{na}/(\tau_{na} + \tau_{ar})$ from the annual precipitations, in all nearly 30% is washed away. With a density of precipitation of $1 \cdot 10^{-1}$ t/year $\cdot$ km^2, the annual wash-off would be $3 \cdot 10^{-2}$ t/year $\cdot$ km^2. With the amount of precipitates of 500 mm, the average concentration in surface waters will significantly exceed the maximum permissible concentration (by up to 30 times). The cited value is most likely an underestimate. Thus, for global radioactive fallouts it is known [5] that the rate of wash-off in the first year is on the order of about a magnitude greater than in subsequent years. There are serious grounds to believe that a similar effect will occur for precipitations of mercury as well.

The subsequent conversions of mercury and its compounds into the very toxic methyl form [10] aggravates this situation. However, this question pertains to the behavior of mercury in the hydrosphere, which is not examined by this model.

CONCLUSIONS

The studies conducted using mercury as an example indicate the need to consider the interaction of different environmental media when establishing standards for the concentration and emissions of dangerous substances. From the data obtained it follows that the emissions of mercury into the atmosphere may create dangerous pollution of soils and bodies of water, at the same time that the pollution of the atmosphere itself will remain at a permissible level.

The features of the mercury balance: the inclusion of local precipitations in the global cycle and the possible impermissible pollution of the waters of dry land through the atmosphere, require a limitation of the emissions of mercury on a global scale.

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HUMAN RISK ASSESSMENT BASED ON LABORATORY ANIMAL STUDIES

D. G. HOEL

Possibly the greatest uncertainty associated with environmental decision making involves a process referred to as human risk assessment. This procedure in its simplest form is concerned with the prediction of the effects on human health by a constant exposure level of a single environmental agent which typically will be a chemical compound. The complexities associated with varying exposure distributions and possible synergistic activity between agents are not really understood and most often ignored. Nevertheless, if reliable methods for predicting health effects at given exposure levels due to a single agent were available, then the environmental decision process will have made considerable progress.

Among possible adverse health effects, carcinogenesis has received the most attention from a human risk analysis standpoint. The reasons for this no doubt vary from the psychological to the relative ease in interpreting qualitatively from laboratory rodent studies to man. Therefore we will discuss primarily methods of risk assessment associated with carcinogenesis. The techniques, however, will often equally apply to other irreversible processes such as teratogenesis and mutagenesis for which the relationships of experimental laboratory findings to man's health are not as clear.

The risk assessment process ideally will involve a mix of both human data and laboratory findings. The laboratory data are clearly essential in two situations: (1) For those cases in which a new product or a greatly increased exposure of an old product is proposed (e.g., NTA as a detergent additive) and for which no human data are readily available. (2) For those situations in which the human data are either of low quality or extremely difficult to interpret (e.g., organics in drinking water). These situations are not meant to minimize the value of human data in risk assessment. There have been many examples where epidemiological methods have identified human carcinogens such as angiosarcomas and mesotheliomas associated with environmental exposures to vinyl chloride and asbestos, respectively. Recently the NCI has produced county cancer incidence maps by cancer type which should give good leads to environmental "hot spots." Possibly the most important need for human data is with the testing and validation of animal models which are intended to predict the human response.

Finally, it has been estimated that the majority of human cancers are due to environmental agents. If so, the needs of human risk assessment in carcinogenesis come basically down to (1) the identification of those environmental components which are human carcinogens and (2) the determination of the degree of carcinogenicity and the identification of susceptible subgroups in the population.

DETECTION

The National Cancer Institute has a major bioassay program for the detection of chemical carcinogens. This program has upwards of 500 chemicals under test in both rats and mice, each at two dose levels. Using both sexes, eight treatment groups of 50 animals apiece are studied. Since lifetime chronic testing is employed, the screening for each individual compound is expensive in terms of both time and money.

From a risk assessment viewpoint there are several difficulties with using data derived from standardized protocols which are designed primarily for detection purposes. First of all, priorities based upon environmental considerations are developed for compound selection. However, environmental considerations should also influence the size of particular assays. This relates to the ability of the assay to detect with statistical confidence a given increase in carcinogenic activity over background levels. Clearly not all the compounds under test are of equal environmental concern. A second need of risk estimation methods is for dose response data. Often the results of detection assays which involve only one or two dose levels are of little use in estimating low dose responses. However, without some prior knowledge concerning the dose response curve, efficient protocols can not be produced to yield the required dose response data.

More recently, consideration has been given to the use of microbial mutagenic tests as presumptive tests for carcinogenesis. In particular, Ames et al. [1] has developed various tester strains of Salmonella which combined with liver microsomes produce results highly correlated with those found by chronic animal studies. Because of its speed and low cost, this bacterial assay may prove to be an effective prescreen for the chronic carcinogenesis assay. Denote by α and β the prescreen's type I and type II errors (i.e., false positive and false negative) and let p be the incidence of true positives in a collection of compounds requiring carcinogenic determinations. Then the following table indicates the increased testing efficiency one would obtain by applying the life-time animal assay to only those compounds which had previously been prescreened positive.

TABLE 1. EFFICIENCY VALUES REPRESENTED BY THE RATIO OF THE PROBABILITY OF DETECTION GIVEN PRESCREENED POSITIVE TO THE PROBABILITY OF DETECTION GIVEN NO PRESCREENING.

p=0.1

			α	
		0.01	0.05	0.20
β	0.01	9.2	6.9	3.5
	0.05	9.1	6.8	3.5
	0.20	9.0	6.4	3.1

p=0.01

			α	
		0.01	0.05	0.20
β	0.01	50	17	4.8
	0.05	49	16	4.6
	0.20	45	14	3.9

Upon examination of the tabled efficiencies one may conclude that if the prescreen procedure has reasonable error probabilities and if testing resources are limited in relation to the number of compounds requiring testing, then substantial savings can be made by applying prescreens.

The correlation between the microbial mutagenesis assay and the animal carcinogenesis assay has so far been a qualitative one. The prospects of a quantitative relationship are unknown at this point. Therefore the application of the results of a microbial assay to risk assessment and quantitative extrapolation to man remains in doubt.

EXTRAPOLATION

The second phase of risk assessment deals with the quantitative aspects of environmental agents. Given that a compound has been determined to be carcinogenic and that it is impractical to totally remove it from the environment, a determination must be made as to the possible effects on human health. Assuming that absolute safety cannot be assured with the presence of an established carcinogen, quantitative estimates of risk are needed.

Currently, risk estimates are obtained statistically by a two step process [2], [3]. First, using a particular mathematical function to represent the relationship between dose and response, the animal effects are estimated for a predetermined level of exposure which is typically much lower than the experimental dose levels. Conversely, an exposure level may be estimated from a predetermined effect level. The second step of the risk estimation involves the extrapolation of the estimated low dose results from the animal data to man. This effort has generally been one of predicting the median man response from that of the median mouse without much attention being paid to the heterogeniety of human population with its possible susceptible subgroups.

Two types of dose models have been used to describe the single risk effects of cancer. The first type functionally relates cumulative tumor incidence with age and is often referred to as a time-to-tumor model. The two mathematical functions which have received the most attention in time-to-tumor descriptions are the log normal and the Weibull [4], [5]. To bring dose effects into the picture, particular parameters in the models are functionally related to dose. Recently, the Doll and Hill data on British physicians and their cigarette smoking histories have been analyzed by both models [6]. The available data seemed to fit the log normal and the Weibull equally well.

The second type of model simply relates dose with total incidence and a number of mathematical functions have been applied. With both types of models there usually are not sufficient data to determine which model best describes the data. However, when one extrapolates to the very low dose levels there are often relatively large differences in the estimated responses. For example, if one were interested in an incidence of 10^{-8} over the background incidence, then there may be a factor of 1000 in the estimated doses which corresponds to this incidence.

In order to avoid the difficulties with choosing a mathematical function for the dose response curve, Mantel and co-workers [7], [8] have suggested that extrapolation be based upon an upper bound to the curve. For example, if the lower portion of the dose response curve is concave upwards then a linear extrapolation would provide an upper bound. Using a conservative upper bound approach unfortunately may produce estimated dose levels which are unrealistically low. The quantitative differences of incorporating such an approach have not been investigated.

Recently the stochastic models described by Armitage and Doll [9] have been studied from a low dose extrapolation viewpoint [10]. These models describe the carcinogenic process as consisting of an initiation period which is composed of a finite number of stages each of which has a rate approximately linear in dose. The initiation period is then followed by a random induction time which is assumed to be independent of dose. Thus the incidence rate at time t with dose d and induction period F can be expressed as

$$I(d,t) = \left[\prod_{i=1}^{k} (\alpha_i + \beta_i d)\right] F(t). \qquad (1)$$

This incidence rate is approximately linear as the dose d becomes small; an obvious question is how close is the incidence rate to linearity at low dose levels. The linear approximation to I(d,t) at $d=0$ is

$$I_L(d,t) = I(0,t) + d\, I'(0,t). \qquad (2)$$

Define d_p as that dose which yields a p increase over the background rate, that is

$$I(d_p,t) = (1+p)\, I(o,t). \qquad (3)$$

The closeness to linearity can then be represented by the ratio r(p,k) of I(d,t) to its linear approximation $I_L(d,t)$ at the dose d_p which is

$$r(p,k) = \frac{I(d_p,t)}{I_L(d_p,t)}$$

and can be shown to have the upper bound

$$\frac{1+p}{1+k[(1+p)^{1/k}-1]}.$$

This bound depends only on the number of stages of the initiation period k and the amount of increase over background p. Selected values are

		p		
		0.1	1	10
k	1	1	1	1
	2	1.02	1.21	2.16
	5	1.04	1.35	3.25
	∞	1.05	1.44	4.17

and from these values one may conclude that the percentage increase over the background level is the determining factor and for small increases such as 10% ($p=0.1$) the incidence rate is essentially linear. Currently statisticians are involved with directly estimating the low dose response assuming the model given by (1). Also they are concerned with obtaining error estimates associated with the response estimates.

After some type of low dose estimate has been obtained, the next step is to extrapolate the estimate to man. Usually not much information on species differences is available and the conversion to man is made without pharmacological input. Hopefully in the future species differences in metabolism, distribution, etc. can be estimated from appropriate pharmacokinetic models. In the meantime information is being studied on species differences in carcinogenesis response so that at least some feeling as to what order of magnitude differences may exist.

In conclusion the problem of risk assessment in carcinogenesis can make modest advances using statistical methodologies. However, until there is a better understanding of the biological mechanisms involved the risk estimates will be fairly crude.

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ENVIRONMENTAL STRESS AND BEHAVIOR: RESPONSE CAPABILITIES OF MARINE FISHES

BORI L. OLLA and ANNE L. STUDHOLME

The search for sensitive and ecologically pertinent measures of pollutant effects on aquatic organisms has stimulated research in a variety of disciplines including animal behavior. Recent work has shown that knowledge of the life habits and requirements of an organism may be used in a variety of ways to assess and predict the effects of contaminants in marine and estuarine ecosystems (for examples, see Olla [1]. Prior to any contaminant experiments in the laboratory, understanding of the organism's normal behavioral repertoire, including its scope of response to natural stresses, may form a sound basis for speculation on its survival potential to man-induced stress. While the organism itself may be able to survive or remain unaffected by a specific contaminant, disruption of components within the ecosystem on which it is dependent (e.g., shelter, food resources) may indirectly reduce its survival capability.

For laboratory studies, baselines may be established using selected behaviors which play an identifiable role in the life habits of the animal. However, the efficacy of the experimental design will depend on the degree to which these behaviors transcend field and laboratory, and are separate and distinct from those induced by the laboratory environment. Departures from these norms will indicate contaminant effects with the results of these studies often directly related to the survival capabilities of the individual or population in the natural environment. However, the confidence with which such extrapolations can be made will depend on the knowledge of normal and the careful integration of laboratory and field results.

Studies to define normal behavior *in situ* may be carried out either by direct observations with the use of mask and snorkel, SCUBA, viewing boxes and submersibles (mobile and fixed units) or indirectly with remote sensing devices such as underwater television, sonar and acoustic tags [1]. Habits can also be inferred indirectly from commercial and sport catches, stomach contents and various sampling techniques primarily used for scientific assessment of populations. All of these procedures contribute information on spatial distributions, activity patterns, daily and seasonal shifts in abundance, feeding and food habits, reproduction, territoriality and other habits and requirements which can be used in the formulation and design of laboratory experiments that are ecologically relevant.

Our philosophy and method of approach of using changes in behavior to measure stress on aquatic organisms can best be illustrated by examples taken from our previously published work. The studies were aimed at furthering our understanding of the comparative aspects of the behavioral response to temperature in selected marine fishes. In this paper, we will limit our discussion to two pelagic species, bluefish, *Pomatomus saltatrix*, and Atlantic mackerel, *Scomber scombrus*, and one demersal species, tautog, *Tautoga onitis*.

We chose temperature as the stress stimulus for our initial studies for two main reasons: 1) it represented a current as well as a future problem for a small but significant number of marine ecosystems being subjected to heated effluents from electrical generating plants, and 2) the design of almost any study on contaminant effects requires consideration of temperature as a primary experimental variable because of the obvious short and long term fluctuations of this parameter in estuarine and inshore marine zones.

Although both pelagic species are quite different taxonomically as well as in the specifics of their life habits, there are, nevertheless, similarities in the way in which they are related to the environment. Both species occupy the upper pelagic zone, travel in schools, and are seasonal migrants. Seasonal movements of these fish appear to be related to changing photoperiod, while their location at a particular time is closely correlated with temperature.

We conducted laboratory studies on each species separately, using small groups of adult fish held under controlled conditions in a 121-kiloliter aquarium [2]. Water quality was maintained primarily by recirculating the water through a filtrant of sand, gravel and crushed oyster shell. Water temperature was controlled indirectly by room temperature and by the addition of water from a well-point located in Sandy Hook Bay. A specialized lighting system simulated diurnal changes in light intensity and duplicated natural seasonal changes in photoperiod.

Both the bluefish and Atlantic mackerel possessed a clearly defined diurnal rhythm of activity although they swam continuously day and night [3,4]. Continuous swimming in Atlantic mackerel was not so surprising since they lack any hydrostatic organ, making swimming obligatory to maintain their position in the water column. The bluefish, although possessing such an organ, also swam continuously, but at much lower speeds and with a higher degree of variability, especially at night. Both species generally swam around the tank in a school, although the bluefish were more variable in this activity especially at night.

The introduction of live food (small bait fish of various species for bluefish; grass shrimp for Atlantic mackerel) caused an almost immediate breakdown of schooling with the fish feeding more or less as individuals (for bluefish, see Olla, Katz & Studholme [5]; for Atlantic mackerel, Olla, personal observation). As would be expected for schooling animals inhabiting the upper pelagic zone where light levels are relatively high, the fish were highly visually oriented, using vision as a primary modality for feeding.

While the introduction of food would cause a breakdown in the integrity of the school, the introduction of a "fright" stimulus had the opposite effect. Stimuli such as a sudden flash of light, especially at night, a splash at the surface, or the sudden appearance of an observer above the aquarium would cause an increase in cohesion and speed. At times, the initial response to a startle stimulus would be for

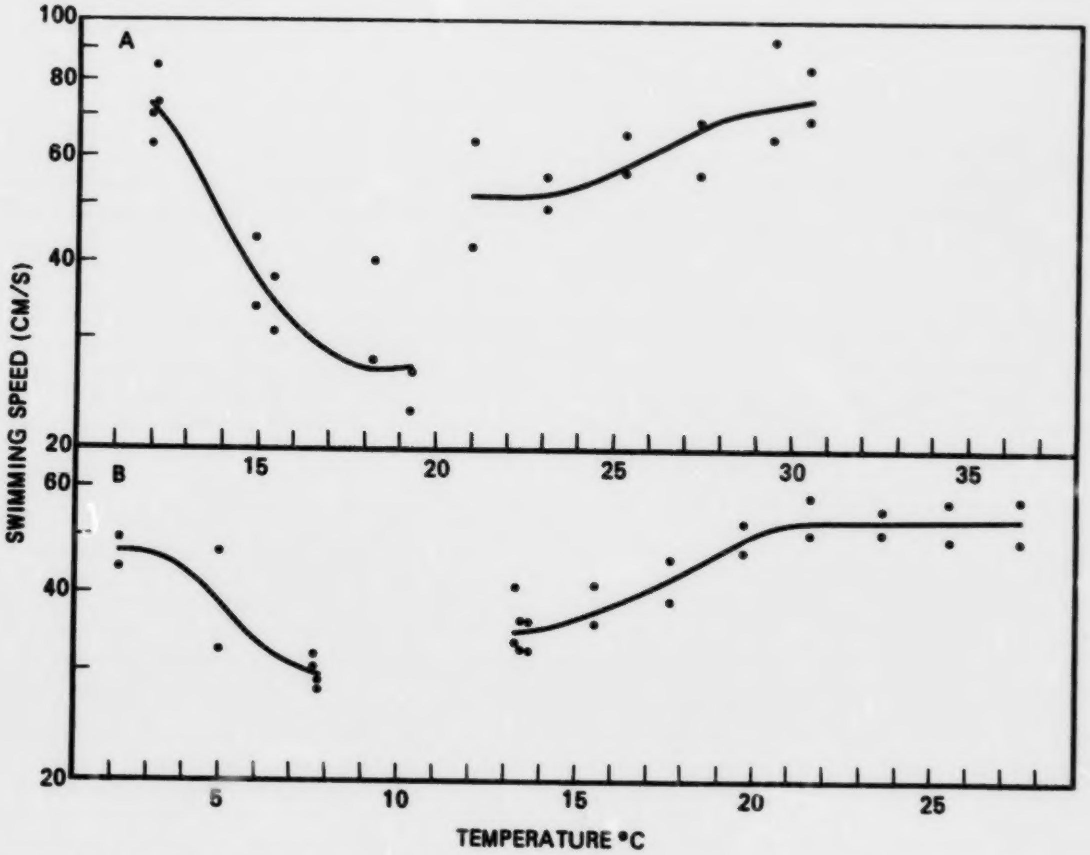

Figure 1. Activity recorded during low- and high-temperature experiments for (A) adult bluefish and (B) adult Atlantic mackerel. Points represent the high and low mean swimming speeds for 4- or 5-day periods at the mean temperature for each period. Relation between activity and temperature is indicated by a median curve (after Reference 4).

the animals to separate, followed within several seconds by regrouping, with the fish significantly closer than before the introduction of the startle stimulus. The fish were highly responsive to any altering stimulus both day and night with avoidance being manifested by increased speed and reduced interfish distance.

Initial acclimation levels for both species (adult bluefish, 19.9°C; juvenile bluefish, 20.0°C; and Atlantic mackerel, 13.3°C) were based on correlations between temperature and distribution. For bluefish, peak abundance off the eastern coast of North America appears to be about 18-20°C (Walford, unpublished) with inshore appearances in the spring along the Middle Atlantic and New England regions occurring as temperatures reached 12-15°C and departures in the fall at 13-15°C [6]. Limits for distribution of Atlantic mackerel along this coast are from about 7-8°C [7] up to approximately 18-20°C [8] with 12-14°C cited by Dannevig [9] as the optimal range for *Scomber scombrus* in the eastern North Atlantic.

The response of both species to gradual increases in temperature (0.02°C/h) from these acclimation levels was an increase in speed (Figures 1a, b, 2) and a decrease in fish-to-fish distance [10,4]. As temperatures reached stress levels, the daily rhythmic pattern was no longer evident as the fish schooled at high speed both day and night. Juvenile bluefish, in separate experiments, responsed similarly (Figures 2, 3; [4]) even though the rate of rise was more rapid (mean rate 1.38°C/h). Maximum cruising speeds were reached by juvenile bluefish at 32-33°C and by Atlantic mackerel at 20-22°C, several degrees below lethal levels.

The response of these two species to increasing temperatures, based on even the most rudimentary physiological interpretation, was not surprising. However, the responses of the adult fish to decreases in temperature from similar acclimation levels, 19.5°C for bluefish, 7.9°C for Atlantic mackerel [10,4], were most interesting, if not surprising. A decrease in temperature (mean rate 0.013-0.03°C/h) resulted in an increase in speed similar to that observed in response to a temperature increase (Figures 1a, b, 2). As they had at high stressful temperatures, adult Atlantic mackerel reached maximal cruising speeds before temperature reached lower lethal levels, Figure 1b.

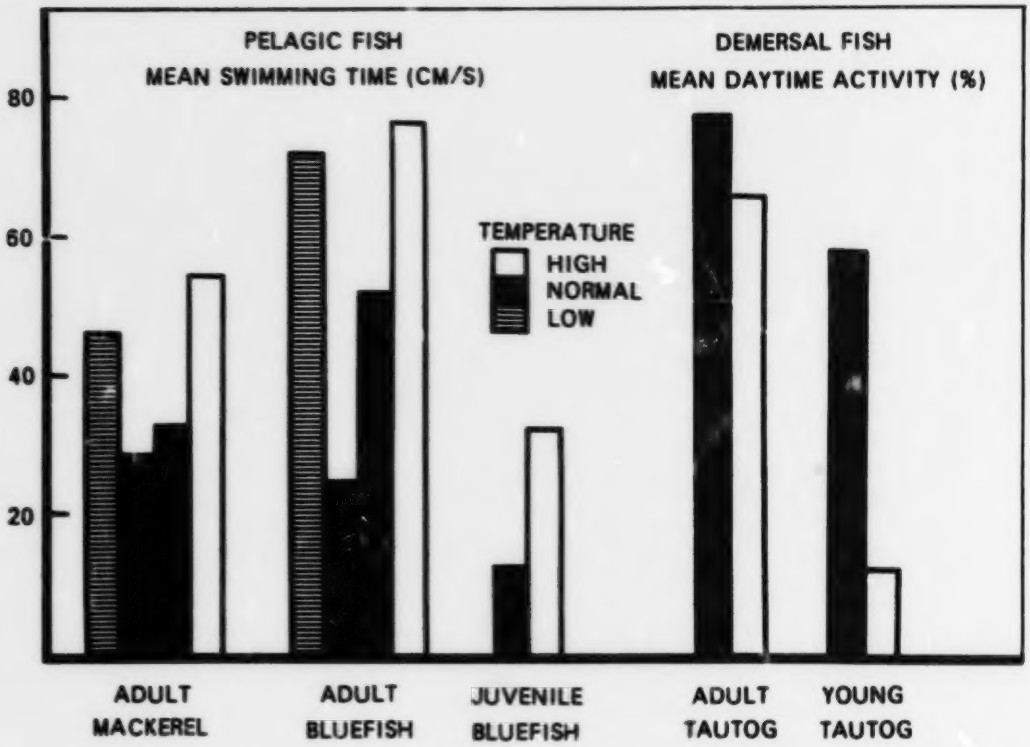

Figure 2. Comparison of activity at normal and stress temperatures for adult Atlantic mackerel; adult and juvenile bluefish; adult and young tautog (after Reference 4).

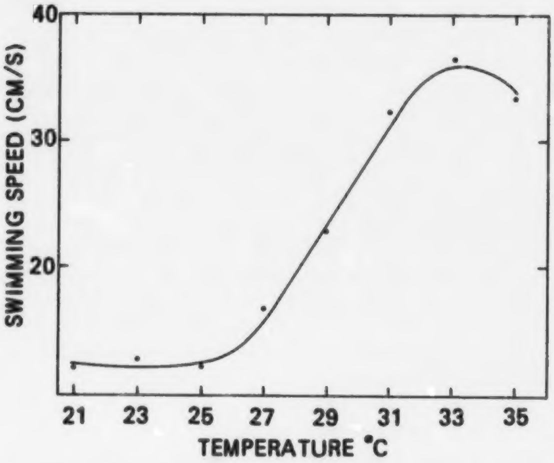

Figure 3. Mean swimming speeds of four groups of juvenile bluefish during temperature rise (after Reference 4).

Although the response to low temperature might be oposite to what would normally be expected, the distribution of these animals in nature is so obviously correlated with temperature that our laboratory findings simply confirmed that temperature is an important parameter influencing their distribution. These pelagic species (it remains to be investigated in other marine pelagics) have the capability of actively avoiding or selecting certain thermal regimes. The data indicate that the temperatures avoided or "preferred" were not specific, but rather fell within a range dependent on the specific environmental requirements of each species.

The similarity in response to both increasing and decreasing temperatures by species with similar normal patterns of behavior reflects what has been termed behavioral thermoregulation ([11,12], for examples and discussion of directed movements in response to temperature). It has been shown *in situ* in fresh water [13] and demonstrated under controlled laboratory conditions [13-15] that certain fishes have the ability to regulate body temperature behaviorally by selecting water temperatures.

Bluefish and Atlantic mackerel, which are not associated with a specific place but rather to specific thermal ranges (as well as with other environmental parameters), have the capability to move in response to changing temperature, thereby avoiding potentially stressful conditions and maximizing their presence in zones which are selectively advantageous.

We suggest that animals such as these possess the capability of generally avoiding stresses including other contaminants. Whether avoidance actually occurs will depend on a host of variables including their motivation to be in a particular area, the characteristics of the contaminant, the ability of the animal to detect it and whether or not it represents, within the context of the animal's scope of responsiveness, a noxious or "danger" stimulus.

In contrast to these pelagic fishes are species which are more restricted both in activity and movements. The tautog, one of two members of the Labrid family found in inshore temperate waters of the western Atlantic, is found on or near the bottom, in association with objects which provide shelter, such as rocks, pilings, jetties, and various forms of vegetation. Our knowledge of the natural habits and requirements of this demersal fish was gained from field studies on populations located in Great South Bay, New York, specifically within the Fire Island Inlet [16,17]. In our studies, we employed various techniques including direct observation with SCUBA, remote sensing with ultrasonic tracking, as well as examination of digestive tracts of captured specimens.

From our direct underwater observations we found distinct differences in the behaviour of the tautog from day to night [16]. During the day they were active and highly responsive, swimming in the water column and feeding along the pilings and rubble in the basin. During evening twilight, the number of fish in proximity to the basin increased. By nighttime, the fish were settled in or on almost any object that afforded cover, lying quiescent and unresponsive throughout the night to the extent that they could be touched or captured with a net. The tautog resumed activity during morning twilight.

Thus, as is the case with the pelagic species, these fish have a diurnal rhythm of activity, but with the important difference that at night they are completely quiescent with significantly reduced ability to respond to altering stimuli.

Results from sonically tracking adult fish (39-50 cm) from July to October showed that these large tautog would move away from the homesite each morning (some travelling as far as 500 meters) and return each night. In contrast with these adults, young tautog (≧25 cm) remained in proximity to the basin throughout the day, close to objects affording shelter.

Underwater observations of the areas where the adults spend significant amounts of time showed large quantities of blue mussels, *Mytilus edulis*. It seemed probable that the daily dispersal of these large fish was related to feeding.

Analysis of the digestive tract contents supported this view, indicating that blue mussels, averaging about 12 mm in length, comprised the major food item. The size of mussels ingested, by even the largest tautog, was limited by the pharyngeal mill at the opening of the esophagus. Since tautog of all sizes are restricted in the size of mussels they can ingest, mussels less than three years old would be the largest potential food resource for which this population would compete. The daily dispersal of the adults from the homesite was probably related to more effective utilization of available resources, reserving mussels at the homesite as a food for the young fish.

These patterns of activity and feeding were typical for this tautog population from July through October. However, as temperatures dropped from the 16-24°C range of summer and early fall to about 10°C in November, we no longer saw tautog larger than 30 cm. This corresponds to the results of Cooper [18] who found that fish of similar size moved out of Narragansett Bay, Rhode Island, to winter offshore in a relatively dormant state. In contrast, our results showed that young fish remained in proximity to the homesite, wintering over in a torpid, non-feeding state. It was apparent that, for the first 3-4 and possibly 5 years, young fish are highly restricted in their movements, associating closely with the shelter throughout the year regardless of temperature.

There are a number of possible reasons for shelter dependence, but one of the most obvious and important for young and adult tautog is protection from predation, especially critical during the periods of lowered responsiveness. It seemed probable that this high degree of dependence on shelter might well limit or preclude any ability to avoid or escape potentially lethal environmental stress, and we hypothesized that tautog, particularly the young fish, might have different behavioral capabilities for response than we had observed with pelagic fishes.

Based on this premise, we tested the response capabilities of young tautog in the laboratory to high, stressful temperature. Two experimental aquaria (1,400 and 1,500 l) isolated in temperature-controlled rooms and equipped with lighting systems which simulated day-night cycles, were used for testing [19]. One to two clay drainage tiles were placed on the sand bottom of each tank to provide shelter. Temperature was regulated by thermostatically controlled units. In each of four tests, two fish of nearly similar size were acclimated at 19.8-21.1°C while observations of behavior patterns were recorded.

After an initial period of adjustment to the laboratory, the fish would be active during the light period, swimming about, searching for food and engaging in aggressive behavior. The larger of the two fish was always dominant, occupying the shelter, and aggressively defending it against the subordinate. The subordinate would dig a depression in the sand adjacent to the aquarium wall, which would serve as a shelter site. When small clumps of mussels were placed on the sand, the dominant fish, if not satiated, would defend this area, chasing and nipping at the subordinate if it tried to feed. At night, both fish would remain generally inactive and quiescent.

The agreement between behaviors observed in both field and laboratory again indicated that these patterns transcended both situations and could be used as baselines in evaluating thermal stress.

As temperature increased from acclimation levels of 19.8 to 21.1°C (mean rate 1.26°C/h) at about 28°C (absolute levels varying among fish), activity decreased as association with shelter increased. As the temperature was held at about 30°C (the level varying within a 2°C range between tests), the activity of the fish diminished still further, Figures 2, 4, and they became generally unresponsive, showing little or no motivation to feed (Table 1). Aggression decreased to the extent that the subordinate fish, now highly motivated to enter and share the shelter tile, could do so without being attacked by the dominant (Table 1). Preliminary findings on the effects of high but sublethal temperatures on adults, indicated that activity as well as aggression was significantly reduced, Figure 2.

The decrease in activity and responsiveness and the accompanying increase in association with shelter

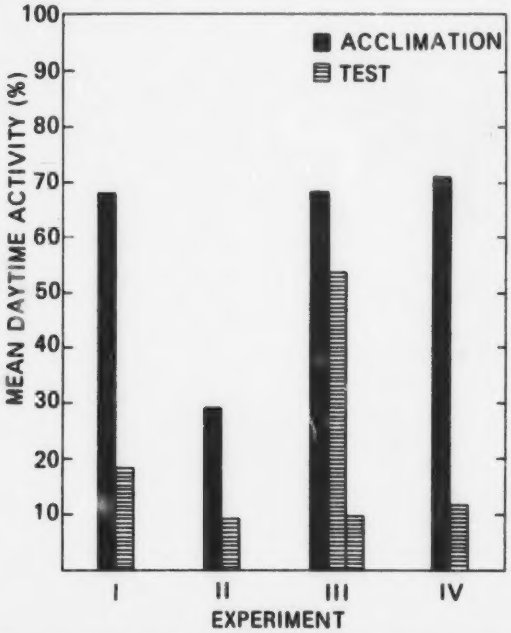

Figure 4. Mean daytime activity of young tautog expressed as percent total day observation time during acclimation (19.8° to 21.1°C) and during tests at elevated temperatures (26.9° to 32.0°C) for four experiments (after Reference 19).

TABLE 1. BEHAVIOR OF YOUNG TAUTOG (*TAUTOGA ONITIS*) AT ACCLIMATION AND ELEVATED TEMPERATURE DERIVED FROM FOUR EXPERIMENTS, INCLUDING AGGRESSIVE ENCOUNTERS (MEAN FREQUENCY), SHELTER OCCUPANCY (MEAN % TIME) AND FEEDING (MEAN WEIGHT IN GRAMS OR NUMBER OF INGESTIONS OF *MYTILUS EDULIS*). MODIFIED FROM OLLA & STUDHOLME, 1975.

	Temperature Range °C	No. of Aggressive Encounters	Feeding		Shelter Occupancy, % Time		
			Wt. Ingested (g)*	No. of Ingestions**	Dominant	Subordinate	Shared
Acclimation	19.8-21.1	16.48	5.50	23.4	37.40	4.88	0.05
Test	26.9-32.0	5.04	1.35	1.3	51.14	24.3	13.72

*Based on three tests in which clam was used for food.

**Based on one test in which clumps of *Mytilus* were used for food.

at high temperature resembled typical nighttime behavior of tautog. Since we had observed tautog in the natural environment seeking shelter when pursued by predators or when startled by divers, it seemed clear that closer association with shelter would serve as protection during periods of lowered responsiveness, whether the stimulus was the onset of nighttime or a stress such as temperature.

When exposure to sublethal temperatures was of short duration, and the temperature returned to 20°C, several of the fish were able to survive, resuming feeding and normal activity within a few days. In the natural environment, they could apparently withstand thermal increases of a transient nature, but if exposure were to be prolonged (dependent also on the rate of increase and temperature attained), survival would be impaired since it does not appear that these fish have the behavioral capability to regulate body temperature by moving to more optimal thermal regions.

Other species, with similar dependence on shelter (e.g., many of the coral reef species) may also be restricted in the capacity to move from a given locale under stressful conditions [20]; (Stevenson personal communication).

Reduced capability for response may also depend on when the stress is imposed. It is apparent that the capability of tautog to respond to or escape altering stimuli at night, when responsiveness is low, would be significantly less than during the day. This is in direct contrast with the pelagic fishes which were highly responsive both day and night.

The contrasting responses of the pelagic species and tautog to thermal stress support our contention that it is important to define, species by species, the normal behavioral capabilities of each as related to their specific environmental requirements before attempting to predict the effects of potentially lethal stresses. While certain physiological and biochemical responses to temperature (and even other contaminants) may be common to a number of species, how an animal may act when subjected to stress is based on its normal scope of behavior. Generalizations cannot be postulated until more is known about species for which only the most meager information now exists.

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PRINCIPLES OF SETTING NORMS OF ANTHROPOGENIC INFLUENCES ON THE VERTEBRATE POPULATION

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At present, in connection with man's strong influence on natural complexes, the pollution of the biosphere with industrial wastes, urbanization and the chemicalization of agriculture, the determination of criteria for evaluating the extent of permissible effects of anthropogenic influences on the animal population and ecosystem as a whole is becoming the main topic for ecological study. From the point of view of the influence on the commercially valuable animal population it is necessary to determine the permissible burdens which either would have no influence on these populations or would have an insignificant effect on them. In the latter case such an effect should not cause a sharp decline or increase in the number, a decrease in animal vitality, and should not influence normal reproduction in the population. For example, the overcatching of animals as well as the undercatching would be of great harm to their protection. Therefore at present, the concept "the protection of animals" includes their wise use and reproduction [1]. On the other hand, with respect to dangerous animals, it is essential to establish minimal standards of influence, which are sufficient to disrupt the successful existence of the population and sharply decrease the number or even completely eliminate individuals of this species in a given region (or throughout the entire area).

The history of the influence of human activity on the commercially valuable animal population on USSR territory yields examples of both negative and positive results. The depredatory utilization of a number of species of valuable mammals, elk (*Alces alces*), saiga (*Saiga tatarica*), beaver (*Castor fiber*), sable (*Martes zibellina*) and other species, had led to their near complete extinction toward the end of the 19th and beginning of the 20th centuries. The ban on hunting these animals and subsequently the wise utilization of a part of the population enabled their number to be restored. For example, the beaver, which at one time populated nearly the entire forest zone of the European part of the country and were encountered beyond the Urals, at the beginning of this century remained only in four small territories far from each other: in the Dnepr River Basin, in the Don River Basin, in the North Trans-Urals along the Konda and Sos'va rivers, and along the upper reaches of the Yenisey River. Measures were taken to protect the beaver and increase their number. Since 1922 the hunting of beaver has been prohibited everywhere. Three special preserves were created. Beginning in 1927, the resettling of the beaver began. The scope of reacclimization grew particularly after the war. From 1946 through 1970, 12,017 beaver had been resettled.

By the end of the 1960's, as a result of measures taken in the USSR, the beaver had settled a territory approximately the size of its area in the 17th century, and the number of beaver reached about 90,000. The increased number of beaver made it possible to organize their commercial hunting, which gradually increased from 537 in 1963 and 1964 to 2376 in 1969 and 1970. In the RSFSR, from 1969 through 1975 the number of elk increased from 455,000 to 640,000; saiga from 135,000 to 330,000; wild boar (*Sus scrofa*) from 71,000 to 131,000; and beaver from 64,000 to 89,000 [2]. The regulated hunting of these species of animals at present does not threaten their population and is not causing a sharp decline in their number. All this is so in spite of the fact that commercial hunting of these species is very intensive. For example, annually (from 1957 to the present) in different years from 30,000 to nearly 200,000 saiga alone have been bagged.

In our age man is developing the natural resources of all the continents and oceans. A large number of species of animals of the world's fauna, including mammals, have in some way become involved in the sphere of human economic, cultural and scientific interests. And the regulation of population processes, which is based on scientific data, is now already within reach.

The principles of setting norms of man-made influences on the animal population should be founded on specific knowledge of the dynamics of the number, the age, sex and distribution patterns of the population, the ability to reproduce (intensity of reproduction) of each species, its food base (the availability under natural conditions of a sufficient amount of food), on the one hand. On the other, it is essential to consider the permissible terms and means of removing a part of the animals from the population — a part that can be quickly restored in the process of reproduction.

The setting of norms of any influences should be based only on in-depth scientific research.

As a rule, each species of vertebrates populates its own area not in its entirety, but only individual places, occupying only the ecosystems suitable for its existence. The degree of proportionality of the population depends on the specifics of the demands of the species on the sphere of habitation, on the place used for purposes of food, and on the natural geographical features of the territory. In different ecosystems the density of the animal population is far from identical. The existence of a number of gradations of settlement attests to the varying degrees of suitability of biogeocenoses to the life of the species and makes it possible to judge their demands on the surroundings. At present we know that the number of animals populating individual areas and entire regions is far from stable and fluctuates greatly from season to season and year to year.

The dynamics of the number in the mammal population is to a certain extent specific for each species. The basic biological traits characteristic of the type of dynamics of the number of animals are the fertility rate and life expectancy. The fertility rate is historically connected with resistance to unfavorable influences of the sphere of habitation and the average life expectancy of individuals. The appearance of adaptations is accompanied by a corresponding lowering of the fertility rate. The animal fertility rate is an adaptation which arose in the course of evolution and offsets the death rate. The balancing of reproduction and death, which ensures relative stability in the population under relatively stable conditions of existence, has deep historical roots.

Especially well defined are the fluctuation in number among massive, rapidly multiplying species, for example, among many rodents and small predators. Fluctuating greatly is the number of certain ungulates (the wild boar [*Sus scrofa*], roe deer [*Capreolus capreolus*], the caribou [*Rangifer tarandus*], the saiga [*Saiga tatarica*], and several others). Among relatively rare and slowly multiplying species, for example, among large predators, the number is more stable from year to year.

The causes for the inconstancy in number of animals are quite diverse. At the basis of this phenomenon are changes in the intensity of reproduction and the rapidity of the dying out of the population, which in turn depend on changes in the conditions of their existence. The changes in number are directly influenced by climatic conditions, the provision of food, the number of predators, and the spread of parasites and agents of infectious diseases.

The change in number of a majority of species has a certain, although not strictly defined, periodicity. For example, the duration of the cycle of change in number of the Arctic fox (*Alapex lagopus*) is 3 to 4 years. For the squirrel (*Sciurus vulgaris*) and hare (*Lepus timidus*) the duration of the cycle varies in different parts of the area of distribution. In the taiga zone great upsurges in number occur every 9 to 11 years, in the southern part of the area somewhat more frequently, but after less specific time intervals [3-5].

At the basis of the principle of setting norms of the process of hunting the population of commercially valuable species is the seasonal change in the number of animals.

The minimal number of a majority of species is observed at the end of winter and in the spring prior to the beginning of reproduction. In autumn, as a rule, the highest number of animals occurs. At the same time, the magnitude of the number, as compared with the number of animals in the population in the spring, is directly proportional to the fertility rate of the animals. Among small mammals (rodents and insectivora) the seasonal changes in number may reach hundreds of times. Among large animals these fluctuations are significantly lower. Thus, for example, the annual increase in the elk herd reaches 15% of the number in spring [6]. During the winter, when as a rule animal reproduction does not occur, the number of individuals in the population decreases as a result of the natural death rate, unfavorable climatic conditions and so forth, and reaches a minimum in spring. Depending on climatic conditions of the year, the spring minimum in number can vary in different years. By knowing the spring number of animals and the fertility rate of the species, we can determine the reproduction intensity in comparison with the conditions of the year and calculate the magnitude of the fall number, which will also determine the norm for the bag of animals. For example, the number of saiga in Kazakhstan in March-April 1974 was 1.2 million. In the spring, after calving, the number grew to 1.7 million, which made it possible to shoot 25% of the herd [7]. The indices of reproduction of a species or population are very significant when setting the norms for the yield of hunting. Thus, relatively similar species of marmots have different fertility rates. For the Menzbier marmot (*Marmota menzbieri*) there are 20 young for each 100 adults and immature adults; for the red (*M. caudata*) and gray (*M. baibacina*) marmot there are 30 to 40 young; for the bobac (*M. bobac*) 40 to 50; and the tarabagan (*M. siburica*) more than 50. Without considering this varying reproductive ability, it is impossible to correctly plan hunting. If you remove from the population a number of marmot exceeding the reproductive capability, it is possible not only to decrease its number, but also to wipe it out.

Different populations of the same species, which live under different conditions, also differ in their reproductive abilities. The elk in the European part of the USSR usually give birth to two young, while the elk of the Trans-Baykal and Primor'ye regions almost always give birth to one.

The different populations of sable have different fertility rates. In the Yenisey region of Siberia the fertility index of the sable is 3.2, while in Kamchatka it is 4.0. The significance of these biological traits of populations must be considered when planning hunting, for determining the possible percentage of the take from the population, so as to preserve the reproductive capability of the breeding stock.

The fertility rate of a species also depends on the conditions of the sphere of its habitation and can change from year to year within the same region. The reasons for this may be the result of different factors: food, climatic, physiological, the sex and age structure of the population [8].

Removal from the population of a part of the individuals improves the conditions of existence of the animals during the period of unfavorable winter conditions; the total burden on the food base decreases and the amount of food per animal increases. Thinning of the population decreases the possibility that widespread epizootics will appear.

The removal of animals from the spring population can not be permitted, since such an action decreases the reproductive capability of the population and may lead to a sharp decrease in the number of animals.

Even for large species of animals there are unfavorable years, when the effect on this species results in a long-term depression of its number. Such was the case in Primorskiy Kray with the squirrel in 1964, when the number of this little animal was very low, and in order to quickly restore it, the hunting of it had to be banned. But this was not done, and the preparation of pelts that year decreased sharply (in all, 8000 pelts were prepared, instead of the 105,000 to 277,000 in years when the number is normal, or the 30,000 to 54,000 in years with a minimal number). As a result of hunting, the number of squirrel decreased even further and its restoration in subsequent years proceeded at a very slow pace, which was reflected in the decrease in its bag for a number of subsequent years [8].

At present the increasingly more intense protection of animals does not always produce the desired results. In a number of regions of the USSR the increased number of ungulates is creating higher burdens on pasture lands, depressing natural reforestation, and frequently results in the death of the forest plantations of valuable types of trees, especially the pine (*Pinus silvestrus*). This situation has been observed in a number of reserves in the central oblasts of the USSR. According to the data of [9], elk have done considerable damage to the timber industry. During the period 1959 to 1968, in Altayskiy Kray the are of timber crops killed off as a result of stripping was 8500 hectares, which brought damages in the amount of 1.021 million rubles. Herds of saiga came into conflict with agriculture and sheep raising. Large herds of wild caribou, which pasture on slowly regrowing mosses, are creating serious difficulty for the further development ot domestic caribou breeding. The increased fertility of the wild boar population in the central oblasts of the European part of the USSR has led to a sharp decrease in the number of wildfowl on hunting grounds, to outbreaks of dangerous infectious diseases and to increased harmful influences of these animals on the productivity of agricultural lands. As a result, the government is sustaining huge losses, numbering in the millions of rubles [10].

At present in most regions of the USSR the large predators, which regulate the number of ungulates and, being scavengers, single out from the population the weakest and least valuable animals, have been almost entirely exterminated. Therefore, man should assume the role of the predators on the population of herbivorous animals.

The reasons for the artificial removal of part of the population, regulation of the norms and terms of bagging animals are formed from precise knowledge of the number of exploitable species and capacity (suitability to the life of the lands). The optimal variant occurs when the number of animals is in complete correspondence with the capacity of the lands characteristic of the species, i.e., when in providing pasturing ungulates with fodder to the full extent the pastures are not degraded into classes of lower productivity, and the productivity of the population of the ungulates themselves is the highest.

Consequently, the extent of the annual take of animals from the populations should be equal to the annual increase in their number, under the condition that the optimal number of this population be maintained. At the same time, the quantitative aspect of the burdens of hunting still has not resolved the matter. It is also important which animals are bagged — males or females, young or adult animals, in what combinations and in what proportions [10].

The negative consequences of taking from the ungulate population only adult animals leads to an impermissible lowering of the age of the population and fragmentation of the animals of the herd, to the inefficient use of fodders in the biogeocenosis. Thus, in Volgogradskaya Oblast, as a result of sport and commercial shooting only of adult animals, the elk population grew younger. Calves there formed 49% of the herd [11].

In Western Europe and on some hunting reserves of the USSR the shooting of animals in order to obtain valuable trophies, primarily horns and the large tusks of wild boar, is widely practiced. In this case the most vital, physiologically fit and valuable specimens for the reproduction of the population are bagged. As a result, the animals in the population become fragmented, their stability of life decreases, and the available number of genes grows worse.

The preferential shooting only of males leads to two negative consequences for the population: a rise in the percentage of barren females and a decrease in the intensity of sexual selection which facilitates the inclusion in the reproductive process of young males who produce a posterity of poorer quality. In those cases when more females are bagged, this results in a decrease in the productivity of the populations, but, at the same time, increases the intensity of sexual selection, which leads to an increase in the quality (stability of life) of the posterity [10].

Under ideal conditions, when the number of animals in the population corresponds to the capacity of the lands, both sexes and all ages in those combinations and proportions in which the animals are represented under natural conditions should be subject to hunting.

Different means of hunting and terms for taking animals have an unpremeditated selectivity. Owing to the behavior traits of sex and age groups during each specific period of the entire term of activity, certain categories of animals come under the fire of hunters. For example, at the beginning of the hunt for elk, owing to less caution and greater attachment to the sector of habitation, more females are shot, in the middle of the hunting period males and females are shot with equal frequency, while at the end many more males are bagged [10]. At the same time, the expenditures of time to bag animals increase from the beginning to the end of the hunting season.

The majority of means of hunting ungulates have an unpremeditated selectivity. Thus, when hunting wild boar with dogs, young females are primarily bagged, while when hunting from a blind, adult male boars more frequently come under fire.

The artificial regulation of the number of animals, with due regard for the age, sex and distribution patterns of the population, its ability to reproduce, and the potentials of the lands, makes it possible to achieve the maximum achievable product.

On the territory of the RSFSR, as a rule, the number of animals taken from the population during the hunting period is significantly less than the permissible hunting yields, see Table 1.

TABLE 1. THE NUMBER OF SHOT ANIMALS OF SEVERAL SPECIES ON THE TERRITORY OF THE RSFSR IN 1974 (1000's) AND THE NORMS OF THE PERMISSIBLE HUNTING YIELDS ON THE POPULATION [12-14].

Species of Animal	Counted	Shot	% of Taken Animals	Permissible Level of Hunting Yield, %
Waterfowl	9275	1799	19.4	35
Elk	184.4	14.1	7.6	20-25
Deer	14.8	0.6	4.7	10-15
Roe Deer	3.2	0.3	6.2	10-15
Caribou	—	—	10-12	—
Saiga	—	—	—	40
Wild Boar	61.8	6.8	11.0	up to 50

Many species of vertebrates have adapted to the regular effects of hunting [15]. Therefore, the ceasing or sharp curtailment of its intensity at times results in unfavorable consequences. The number of many species of commercially valuable animals on lands long unfrequented by hunters is often lower than on lands regularly developed for hunting.

For example, on the Konda-Sos'va preserve, following a 22-year ban on hunting, there were significantly less sable than on the lands adjacent to it. In sable populations touched only occasionally by shooting, young individuals made up 10.5 to 14.3% of the total, adults from 21.7 to 38.7%, and the old from 47.0 to 62.4% (an extremely large number of old). In places where normal hunting and trapping took place, the sable populations were made up of 54.0 to 62.0% young, 36.3 to 46.6% adults, and 1.2% old (the healthy population).

Quite different principles of the effect on the animal populations are at the basis of the struggle against agricultural pests (insects and rodents) or carriers of natural infections of man and agricultural animals. In such cases it is a matter of the complete removal of specific species from the ecosystem or a curtailment of their number to the point that they no long represent an appreciable danger.

A good example of the long-term effect on the mammal populations from the curing of a natural plague outbreak in Priaral'skiye Karakumy is cited [16]. In the process of ridding the territory of plague, a breakdown of the epizootological chain occurred: the warm-blooded host, a large sand eel *(Rhombomys opimus);* plague microbe; fleas. An exception to this occurred where microbes continued to exist in desert ecosystems through long-term (3-4 yr) maintenance of a low number of rodents. These rodents are elementary hotbeds forming a most stable site for the preservation of the agent in nature.

Extermination work using poison bait and other means was carried out on hundreds of thousands of hectares, with subsequent "mop-ups" — the destruction of remaining small colonies of rodents. This work was preceded by much scientific research.

It is interesting to note that as a result of the extermination of the large sand eels on vast territories, predatory birds and mammals have either disappeared from these regions or shifted to feeding on other types of animals. Consequently, the effects on one species in the ecosystem caused a significant influence on the populations of other species and on the entire ecosystem as a whole. Moreover, the extermination of the large sand eel has led to a change in the plant community at their colonies, which facilitated an improvement of the food base for other herbivorous animals. Many similar examples could be cited.

Some anthropogenic influences on the landscape result not only in a decrease of the number of animals, but even in the complete extinction of entire populations. The complete felling of forests, the plowing up of virgin lands, the flooding of river floodlands, and so forth cause the disappearance of some species of animals and the appearance of new species on "cultivated" territories.

The extermination of a species or the sharp decrease in its number on a relatively small territory does not lead to its disappearance. Following the cessation of the influence on the population or a part of it, through reproduction of the remaining individuals and the moving in from outside, the number of animals may soon be restored. For example, the population of elk in the European part of the USSR at the beginning of this century had been greatly thinned, while in the central and southern oblasts it had been totally exterminated. Owing to protection the elk quickly resettled and at present the area of their distribution has reached the Northern Caucasus.

Very similar phenomena are observed in fish populations in the case of fishing. As a result of long-term intensive fishing and irrational management, the reserves of sturgeon in the Caspian by the 1940's had entered a depressed state. The catch was no more than 50,000 quintals. To re-establish the reserves of these valuable commercial fish (primarily the sturgeon), the following measures were taken:

—the complete ban on commercial fishing for a period of 8 to 10 years;

—the establishment of commercial size and limit (quota of catch);

—reconstruction of the food base of the Caspian sturgeon by introducing new species of mollusks and Polychaeta (*Nereis—Nereis pelagica*);

—improvement of the coastal water regime (purification of sewage), observance of permissible norms of pollution by oil enterprises, regulation of exploratory blasting work;

—artificial breeding.

As a result the present catch of sturgeon in the Caspian has increased to 250,000 quintals. In the future it will reach 500,000 quintals.

Fishing has a multiple influence on the school of commercial fish. By taking a part of the school, fishing on the one hand, by thinning the population, raises the supply of food for the remainder of the school, which is connected with a change in the growth rate of the individual fish, the age of achievement of sexual maturity, and the age limit. Selective fishing, when using any method of catching and nets with different sizes of netting, in removing some part of the population, tells on the change in the population structure, and thereby also on its reproductive properties [17].

By removing part of the school, fishing inevitably changes the intensity, and at times event the nature of the effect of the school of fish on its feed base, creating in a number of instances favorable conditions for feeding other species of fish, which consume foods similar to the foods of the species that is the object of fishing. By thinning the school of predatory fish, fishing changes the intensity and nature of its effect on the school of peaceful fish.

Let us take, for example, an elementary food link, the triotroph of our lakes, say in Pskovsko-Chudskoye reservoir: zooplankton — lake smelt (sparling) and pike perch. The crayfish which form the zooplankton are eaten by the sparling, and the sparling are destroyed by the pike perch. The pike perch has practically no predators.

In the unfished reservoir a mobile equilibrium of the food chain is being established: the abundance of phytoplankton determines the number of its consumers — the crayfish of zooplankton; the number and mass of zooplankton in turn determine the number of its consumers — the sparling, and the biomass of the sparling in the final analysis is the cause of the number and biomass of the pike perch.

Assume that fishing aimed at catching the pike perch encroaches on the established natural dynamic equilibrium of these inhabitants of Pskovsko-Chudskoye reservoir. Having caught a part of the school of pike perch, fishing lowers the loss of the sparling school as a result of this predator or, as is customary to say, weakens the press of the predators. An excess number in the sparling school is created, which can be removed from the reservoir. In this case, fishing for sparling replaces the predator, as if assuming the role of the predator.

Thus, the basic natural reserve of the commercial product should be seen in the directed restructuring by fishing of the food interrelationships among populations in the reservoir for the purpose of "replacing the predator." This can be regarded as a direct influence on the biocenosis with the purpose of removing a part of the biomass and converting it into a commercially valuable product.

Another form of fishing activity is indirect, oblique, aimed at weakening the rival relations among species and within a species. In lakes the bream and ruff feed on similar food, bottom invertebrates. The intensive fishing for ruff frees food for the other, more valuable species, the bream, and thereby enables an acceleration of its growth and an increase in the number and biomass.

With respect to schooling fish, for some the school is a defensive means against predators; fishing, in breaking up the school structure, can often make these fish more accessible to the activity of predators. Finally, in a number of cases, fishing changes the parasite relations of commercially valuable fish.

From its effects on the population, fishing is reminiscent of the effect of predators, and the reaction of the population to fishing is in many ways similar to its reaction to the influence of predators. The difference usually is that fishing primarily affects the best, sexually mature part of the school, while predators affect the sexually immature and sick part.

Fishing, by thinning the school, creates more favorable conditions for the supply of food for the remainder of the population and thereby affects the intensity of its reproduction. For intensively fished populations of commercially valuable fish the growth rate is higher and the population fertility rate is greater. However, for all fish populations an increase in the intensity of fishing causes a rise in the growth rate and fertility rate only to specific limits, above which, the regulatory mechanisms of the population are disturbed, and they cease to react to further thinning of the school. This is a very serious signal of overfishing. Species of fish with a short life cycle, early sexual maturation, great replenishment with respect to the remainder, which have adapted to the intensive effect of predators on the sexually mature part of the population, permit an even greater percentage of take of the sexually mature population through fishing. While fish with a very aged population structure, late sexual maturation, with a relatively low replenishment with respect to the remainder following fishing, and which have adapted to a relatively low death rate from predators at old age, permit a relatively small percentage of take with respect to the entire sexually mature part of the school.

Thus, fishing of a specific intensity, different for different species which differ in the nature of the dynamics of the school, might also not disturb its reproduction. This occurs when fishing removes that part of the school, to the removal of which the population is adapted (eating by predators), when fishing can be offset by the regulatory mechanisms of the population, i.e., when fishing appears to be an element of the environment. Given a similar intensity of fishing and, of course, if spawning and the condition of development of the young are not disrupted, the population will be able to exist for many years, annually providing a specific catch [17].

Selectivity (selective action) of the tackle and means of catching depends on very many causes; like fishing efficiency it is the result of the interaction of the tackle and the fish and is determined both by the qualities of the tackle and means of catching and by the qualities of the fish population being caught. The selection of the tackle and means of catching is made in a number of directions: choice of fish of a specific size, quickest growing, specific sex and maturity of sexual products, specific fatness and fat content, and, finally, choice of fish of different stages of fattening.

At present, fishing has on a school of commercially valuable fish a very significant and diverse influence. On fish with a different nature of school dynamics this influence can vary. With respect to a number of species of fish extreme fishing has led to a decrease in their number and a progressive decline in catches. This concerns above all bottom fish with poorly defined fluctuations in number.

The changes occurring in the structure of the population of commercially valuable fish under the influence of fishing are quite diverse. In some cases a sharp decline in the age of the school is observed, in others, in spite of the considerable intensity of fishing, the age structure of the school remains unchanged. Among fish with significant fluctuations, the changes in the structure of the school under the influence of fishing are usually less noticeably defined than for fish with small fluctuations in the productivity of generations.

In order to set correct norms on the size of the fish catch, there must be timely information on changes occurring in the population. Therefore the fishing industry sets the size of the fish catch by taking into consideration two elements: (1) the value of the raw material base at the moment and (2) the prediction of change in the number and biomass of the schools of fish being caught in the future.

Present prediction of the number and biomass of the school of fish provides the industry with information on the maximum permissible catch of each species, the size, age and sex composition of the spawning school, and a qualitative description of the fish. Of great significance in making predictions of fish catches is the description of the food base.

On the basis of predictions not only the total size of the catch, but also its quality are planned. Thus, at the basis of setting norms of anthropogenic influence on the populations of commercially valuable fish and mammals there have been used, in general, the same principles which are based on universal biological laws.

Obviously, pollution with industrial wastes should be considered a no less significant influence, not always controllable by man, on the animal populations.

The Institute of Evolutionary Morphology and Ecology of Animals of the USSR Academy of Sciences for a number of years has been studying the effect on the rodent population of artificial contamination, for experimental purposes, of ecosystems with strontium 90 soil contamination levels up to 3.4 millicuries/m^2 [18]. These studies showed that in the degree of effect of this new ecological factor for animals two periods can be singled out.

First period. The animal population for the first time came under conditions of radioactive contamination. In this instance a strong effect on the population of small mammals is observed. The age, sex and distribution pattern of the population changes. The death rate increases and the life expectancy of individuals decreases. The embryonic death rate increases, the period of reproduction in the population decreases, the reproduction rates decline. The interrelations "host- endo- and ectoparasites" and "victim-predator" become more acute. A change in the animals' behavior is also noted [18]. Radioactive contamination of the ecosystem has its strongest effect on the oldest animals at the end of their life. Such specimens no longer participate in the reproductive processes and usually die a natural death. When they are removed even through the effect of radiation, the size of the population does not decline significantly, since the number of such animals is not great. It was established that in spite of breakdowns in ecology, rodent populations can exist on territories contaminated with strontium 90 up to levels of 1.0 to 3.4 millicuries/m^2.

Second period. The population lived under conditions of radioactive contamination for several reproduction periods. In this instance, owing to natural selection there remain in the population the animals more resistant to radiation, which produce a posterity more resistant to radiation. The population's resistance to radiation in this case increases. The effects of the influence on it of the radioactive factor of the sphere of habitation are less appreciable [18, 19].

Additional radiation with gamma rays of rodents taken from populations inhabiting for 15 years sectors contaminated with strontium 90 and a clean area showed that these animals do not differ significantly with respect to this factor, see Tables 2 and 3.

TABLE 2. LD$_{50/30}$ FOR TWO SPECIES OF RODENTS TISSUES OF THEIR SPLEENS IN POPULATONS ON SECTORS ARTIFICIALLY CONTAMINATED WITH STRONTIUM 90 FOLLOWING RADIATION WITH COBALT 90 AT A DOSE OF 200 r [18,20].

Species	Experimental Sectors	LD$_{50/30}$, r	Aberrant Cells, %
Red Vole	Contaminated by strontium 90	980±26	10.4±1.1
	Control	949±20	9.8±0.6
Wood Mice	Contaminated by strontium 90	600±32	11.6±0.7
	Control	630±25	14.6±0.9

The experiment was conducted on a species highly resistant to radioactivity, red voles (*Clethrionomys rutilus*), and a less resistant species, wood mice (*Apodemus sylvaticus*). Similar results were obtained for both species.

TABLE 3. NUMBER OF CHROMOSOME ABERRATIONS IN CELLS OF THE SPLEEN OF RED VOLES AND WOOD MICE INHABITING SECTORS ARTIFICIALLY CONTAMINATED WITH STRONTIUM 90 FOLLOWING RADIATION WITH COBALT 90 IN A DOSE OF 200 r [18].

Sectors	Experimental Conditions	Number of Aberrant Cells
	Red Vole	
Control	Spontaneously	5.6±0.5
	200 r	9.8±0.6
Contaminated	Spontaneously	6.4±0.4
	200 r	10.4±1.1
	Wood Mice	
Control	Spontaneously	8.2±0.6
	200 r	14.4±0.9
Contaminated	Spontaneously	8.0±1.7
	200 r	11.6±0.7

Thus, certain cases of the adaptation of bacteria populations to various chemical substances and the emergence of DDT-resistant insect populations are complemented also by the case of the adaptation of populations of small mammals to radioactive contamination. Apparently, the emergence of populations resistant to certain contaminations of ecosystems with chemical substances can be a universal biological law.

The problem of setting ecological norms of the contamination of the ecosystem from the point of view of the influence on the mammal population is very complicated. Furthermore, it should be taken into consideration that in forest ecosystems, when there are contaminations by chemical and radioactive substances, the first to die are the species of fir trees, which are significantly more sensitive to this factor than verterbrate animals [21]. In this instance there occur the thinning of the forests and a significant change in the species composition of the animals in the ecosystem, up to the complete disappearance of certain species.

It is impossible not to dwell on the question of the migration of certain elements in the food chains in the ecosystem. At present, when calculating the maximum permissible concentration for freshwater ecosystems, consideration is not always given to an element's propensity to be concentrated in specific trophic levels of food chains. Figure 1 shows our data on the migration of strontium 90 and cesium 137 in some food chains of a body of fresh water [22].

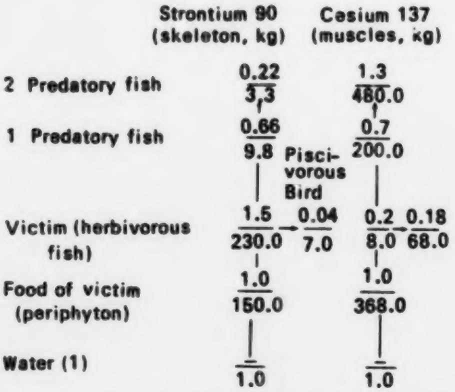

Figure 1. Quantitative distribution of strontium 90 and cesium 137 in the food chain of the zoocenosis of a body of fresh water in relation to the content of the radioisotope in food of the victim (numerator) and the water (denominator) (Il'yenko).

As is evident from the data cited in the figure, the concentration of strontium 90 in relation to its content in the water as the food chain gets longer, decreases in the skeleton of invertebrates. In the secondary consumer — the predatory fish, and in the piscivorous bird — its concentration still exceeds the content in the water respectively by 3.3 and 7.0 times. In the case of cesium 137, the concentration increased respectively by 480 and 68 times.

Moreover, it is necessary to consider the extent of resistivity of the organisms which are at different trophic levels in the food chains, which can differ by tens and hundreds of times. Unfortunately, at present this question still remains very little studied.

Anthropogenic influences on populations of invertebrate animals may have a diverse nature. They can be short-term and periodic short-term (annual); long-term; or permanent. It is evident that, depending on the nature of the influence, the population will react to them in different ways.

Short-term and periodic short-term influences. A decrease in the number of animals through partial removal. Temporary change in the structure of the population. Improvement of the food base for the remaining animals. Heightening of the reproductive ability of the population. Restoration of the number in the next reproduction season.

Long-term influence. Sharp decrease in number. Disruption of the age, sex and distribution patterns of the population. Following the cessation of the influence a slow restoration of the number through reproduction of surviving local specimens and animals moving in from surrounding territories.

Permanent influence. At first a decrease in number, then the complete extermination of the specimens in the population. The population may be reestablished after many years, through migration of animals from bordering territories. There may be adaptation of the population to some anthropogenic influences after the long-term unfavorable effect.

The proposed system does not claim to be complete and as data are accumulated will be supplemented and improved.

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EXTRAPOLATION OF ANIMAL DATA TO HUMAN RESPONSE: AN ASSESSMENT OF THE FACTORS INVOLVED

THOMAS J. HALEY

INTRODUCTION

When the subject of extrapolation of animal data to human experience is discussed, one is confronted with a multitude of problems, all of which impinge on the validity of the data being extrapolated. What were the experimental conditions, and was the experimental design well thought out prior to the initiation of the evaluation? It rapidly becomes evident that very few cases are available in which previously determined animal data indicated a possible human hazard from environmental dispersion of a known chemical entity. The opposite is usually the case where cancer or some other debilitating or fatal condition is first observed in a human population and animal experimentation serves to confirm the hazards associated with such environmental exposures. To further complicate the situation, the degree of exposure and the amount absorbed per unit time are rarely known in most cases of human exposure to potent environmental chemicals. While the physical condition of an experimental animal population is generally known in great detail, that of the human population is often complicated by known or unknown degrees of physical impairment of important body systems.

The purpose of this discussion is to review and place in perspective the various factors involved in extrapolation studies and determine those which complicate our extrapolations and those which might make it possible to forecast possible human hazards prior to their appearance. However, we must consider the fact that environmental exposures in their totality generally involve exposures to multiple chemicals simultaneously rather than a single entity and the sorting out of all contributing factors can be an enormous task. Factors to be considered include: chemical and its physical state (liquid, solid, particles, gas, etc.), route of exposure (gastrointestinal, dermal, pulmonary), rate of absorption, routes of biotransformation, active and inactive metabolites, pharmacokinetic considerations, body distribution and storage, age, physical state (health or illness), routes of elimination and unforeseen events. Means for determining exposure and industrial hygenic practices which assist in assessing the degree of exposure and preventing exposure will also be covered. Selected chemicals known to be involved in environmental exposures will be utilized to illustrate how the above factors become active and assist in extrapolation studies.

INTERPLAY OF THE VARIOUS FACTORS

It would be nice to separate each of the factors, but in reality they are so intermingled that they must, in general, be discussed together. A prime example is exposure to asbestos where both man and animals develop mesothelioma of the lungs and peritoneum from inhalation exposure. Particle size is all important because only particles of $<3\mu$ in diameter and $>20\mu$ in length are more carcinogenic than other particles. Time is also important because animals require exposures of up to two years before pulmonary carcinoma is evident, while humans develop the disease after 15 to 20 years. Nothing is known regarding the development of gastrointestinal cancer from oral ingestion of asbestos by either animals or man although potable water supplies have been shown to be highly contaminated with asbestos fibers. Research in this area should allow a good extrapolation of animal data because the degree of contamination and the particle sizes are known, as is the time interval of exposure.

Another example of environmental exposure via the pulmonary route is the development of hepatic angiosarcoma in animals and man from inhalation of vinyl chloride. Viola's original animal experiments showed liver carcinoma after prolonged exposure to 30,000 ppm of vinyl cholride, but it was only after similar cancers appeared in a small number of vinyl chloride workers that the problem received serious consideration. Again, we were dealing with a concentration/time effect where the amount of vinyl chloride in the environment was unknown. Subsequent animal experiments showed that prolonged exposure to 25 to 50 ppm of vinyl chloride resulted in the development of hepatic angiosarcoma.

Benzidine is another chemical with a long history of problems from an environmental standpoint. The first human chemically induced bladder carcinoma was reported in 1895 but it required many years of research to positively identify benzidine as one of the causative agents. Extrapolation from animals to man was not possible in the early years because there was no animal model. Benzidine induced bladder carcinoma was first seen in dogs fed the material for 7 years. Other animal species do not develop such tumors. This is peculiar because all other related chemicals, i.e., 4-aminobiphenyl, known to induce urinary bladder cancer in man also produces it in the mouse. Furthermore, human exposures are via the pulmonary and dermal routes rather than by ingestion, except in the case of the Japanese kimono painters who develop the disease from "pointing" their brushes while applying benzidine dyes to fabrics. The age factor has been found to operate in the development of benzidine bladder carcinoma; those exposed before age 30 years develop the condition earlier than those exposed later in life. This may, in part, be related to the chemical's long induction period.

The dermal route of exposure allows extrapolation from animal data to the expected human response but, here again, caution must be observed in interpretation of the data because animal skin and human skin are not the same. Moreover, human skin differs in chemical penetrability depending on the area exposed with axillary and inguinal areas giving the most rapid chemical absorption. This is of extreme importance in environmental exposure to anticholinesterase pesticides. However, the chemical itself may influence the rate of dermal absorption. Carbaryl shows a high absorbability on the palm of the hand, a skin area known for its low penetrability. High ambient temperatures can also increase skin penetration by environmental chemicals and cause varying degrees of intoxication. Data are given in Tables 1 and 2.

TABLE 2. RATIO COMPARING VARIOUS SITES TO FOREARM

	Parathion	Malathion	Hydrocortisone
Forearm	1.0	1.0	1.0
Palm	1.3	0.9	0.8
Foot, ball	1.6	1.0	....
Abdomen	2.1	1.4	....
Hand dorsum	2.4	1.8	....
Scalp	3.7	....	3.5
Jaw angle	3.9	....	13.0
Forehead	4.2	3.4	6.0
Axilla	7.4	4.2	3.6
Scrotum	11.8	....	42.0

FACTORS INFLUENCING THE RATE OF ABSORPTION

As has already been discussed, environmental chemicals enter the body via the lungs, gastrointestinal tract and skin, and each of the portals of entry exhibit different rates of absorption related to known mechanisms of transport. Simple diffusion transports many substances through cell membranes. The thickness of cell membrane (ca. 100 Å) and the diameters of the pores in cell membranes (4 to 40 Å) regulate the size of molecule or micelle that can be moved into or out of cells. Even water soluble chemicals of molecular weights of 100 or more cannot pass into erythrocytes. The ionized portion usually does not pass through the cell membrane and its distribution is governed by its pKa value, the pH gradient and active transport. This produces a difference in concentration on each side of the membrane. The nonionized portion, being lipid soluble, is able to pass the cell membrane.

Active transport, which requires energy and enzymatic activity, can cause chemicals to enter cells selectively against an electrochemical or osmotic gradient. Such transport can be blocked by metabolic inhibitors. This is very important where environment exposure involves multiple chemical entities and may

TABLE 1.
EFFECT OF ANATOMIC REGION ON ABSORPTION OF TOPICAL ^{14}C MALATHION AND CARBARYL (URINARY ^{14}C EXCRETION EXPRESSED AS PERCENT APPLIED DOSE)*

Anatomic Region	Excretion								Total Excretion		
	Hours				Days						
	0-4	4-8	8-12	12-24	2	3	4	5	This Experiment	Forearm Control	Ratio
Forearm	0.176	1.557	1.647	2.186	0.767	0.232	0.128	0.142	6.838 ± 2.312	6.838	1.0
Palm	0.133	0.629	1.061	1.867	1.147	0.431	0.321	0.236	5.828 ± 2.913	6.838	0.9
Foot, ball	0.361	0.255	0.269	1.082	2.757	1.320	0.491	0.249	6.787 ± 3.237	6.838	1.0
Abdomen	0.138	2.618	2.774	1.965	1.191	0.388	0.194	0.155	9.377 ± 7.947	6.838	1.4
Hand dorsum	1.199	2.732	3.135	3.357	1.065	0.371	0.314	0.291	12.466 ± 3.956	6.838	1.8
Forehead	1.660	6.994	4.358	6.077	1.816	1.002	0.496	0.774	23.179 ± 9.139	6.838	3.4
Axilla	2.313	12.351	5.380	4.556	2.014	0.978	0.768	0.299	28.662 ± 13.743	6.838	4.2
Carbaryl forearm	0.21	4.85	12.11	23.33	20.49	6.65	3.70	2.54	73.91 ± 21.03	....	....
Jaw angle	4.43	11.30	14.61	10.91	12.83	6.19	4.43	5.17	69.91 ± 19.55	....	....

*The dose was 4 ug/sq. m. All data are corrected for incomplete urinary recovery from the intravenous control data. Six subjects were involved in each experiment.

aid in explaining the aberrant results often reported in the literature. Facilitated diffusion is carrier transport which shows selectivity, saturability and blockade by metabolic inhibitors but does not move a chemical against a gradient. Solubility and concentration of a chemical in tissue fluids are determining factors in the rate of absorption, as are the area of the absorbing surface, richness of the capillary bed and route of exposure. It must be borne in mind that solubility in tissue fluids does not follow the usual form of solubility in aqueous or organic solvent because tissue fluids are mixtures whose overall composition assists in dissolving many chemicals usually considered insoluble.

Pulmonary absorption is usually extremely rapid because of the large absorbing surface and the richness of the capillary bed. Furthermore the pulmonary macrophages can facilitate absorption of insoluble particulates by phagocytosis. Pulmonary irritation can facilitate absorption or decrease it, depending upon the degree of irritation, mucous secretion, ciliary activity or paralysis and the various pulmonary reflexes which can be activated. The concentration of gas, aerosol or particulate is also important. Gastrointestinal absorption is extremely variable and is influenced by solubility, formation of food complexes, susceptibility to enzymatic action, gastric emptying time and the irritability of the particular chemical. The rate of absorption via the dermal route is even more variable, depending upon the chemical, its lipid solubility and the solvent used as a carrier.

TABLE 3. SUMMARY OF BENZIDINE BIOTRANSFORMATION IN VARIOUS SPECIES

Species	Metabolites
Mouse	Monoacetylated 3-OH ethereal sulfate
	Monoacetylated 3-OH glucuronide
	N-Hydrogen sulfate and/or glucuronide
	3-OH-Benzidine glucuronide
Rat	3,3'-Dihydroxybenzidine (?)
	4'-Acetamido-4-amino-3-diphenylyl hydrogen sulfate
	4'-Amino-4-diphenylyl sulfamic acid
	4'-Acetamido-4-diphenylyl sulfamic acid
Guinea Pig	4'-Acetamido-4-aminodiphenyl N1glucuronide
	4'-Acetamido-4-amino-3-diphenylyl hydrogen sulfate
Rabbit	3'-OH-Benzidine sulfate and glucuronide
	4'-Acetamido-4-amino-3-diphenylyl hydrogen sulfate
	4'-Amino-4-diphenylyl sulfamic acid
	N-Glucuronides
	4'-Acetamido-4-aminodiphenyl
	3-OH-Benzidine
Dog	3-OH-Benzidine
	3-OH-Benzidine hydrogen sulfate
	4-Amino-4-hydroxybiphenyl
	Mono- and diacetylbenzidine
	4,4'-Diamino-3-diphenyl sulfate and glucuronide
Monkey	Monoacetylbenzidine
Man	3,3'-Dihydroxybenzidine (?)
	Mono- and diacetylbenzidine
	3-OH-Benzidine
	N-Hydroxy acetylaminobenzidine

ROUTES OF BIOTRANSFORMATION

Whereas many chemicals may not require activation by body tissues, a large variety of environmental chemicals must be activated by liver, kidney, lung or other tissue microsomal enzymes. Moreover, the environmental mixture may contain body enzyme inducers (DDT, methylcholanthrene, etc.) or inhibitors (piperonylbutoxide). Age also plays an important role in chemical transformation; the very young must develop the necessary enzymes and the elderly have lower levels of enzymatic activity. Females tend to metabolize chemicals at different rates than males and in some species and strains of animals, vital enzymes may be missing. This becomes important in the selection of animal models for approximating expected human responses to environmental chemical exposure. Genetic differences, both animal and human, can produce profound effects on biotransformation pathways. There are only eleven known mechanisms for biotransformation of chemicals and the most important ones are oxidation, reduction and conjugation. The reactions are influenced by body temperature with low temperatures reducing and high ones increasing their rates. A reduction in enzyme protein will reduce enzyme concentration and thus decrease the rate of chemical conversion. Here again it is evident that the interplay of many factors determines both the animal and human responses to environmental chemicals. Moreover, the various species biotransformations of a given chemical may differ by several orders of magnitude. It has been suggested that short term *in vitro* biotransformation experiments may give clues to human responses. While the animal data obtained may indicate the possible active metabolites, it would be disastrous to conclude that a given chemical is transformed in the same manner by all species. This is illustrated by the metabolic end products for benzidine shown in Table 3. On the other hand, the biotransformation of vinyl chloride, which involves an epioxidation step (Figure 1), appears to be similar for all species. An increase in urinary mercapturic acid following exposure to vinyl chloride indicates the loss of hepatic glutathtione and subsequent toxicity to hepatocytes resulting in hepatic angiosarcoma. Monitoring of urinary excretion of ethereal sulfate, glucuronide and free phenol can give an indication of the severity of exposure to benzene and a warning that the liver and kidneys have been damaged. Liver and kidney impairment also can

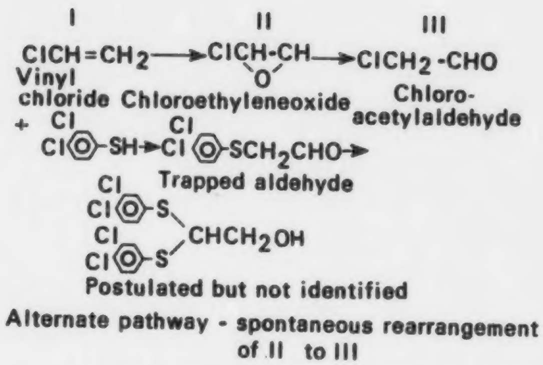

Figure 1. Biotransformation of vinyl chloride by mixed function oxygenase.

have a profound effect on the biotransformation and elimination of environmental chemicals. Thus chemical exposure at low levels can result in both acute and chronic toxicity which can end fatally even though the exposure levels may be below those generally considered to be hazardous.

PHARMACOKINETIC CONSIDERATIONS

The pharmacokinetic study of environmental chemicals has not received the attention it deserves either in animals or man. The measurement of the rate of absorption, tissue distribution and binding, storage (i.e., fat depots), metabolism and elimination must be undertaken if a thorough knowledge of chemical attack and attachment to receptor sites is to be obtained. Unbound plasma levels can be directly related to the level of agent reaching such sites, except with those chemicals producing an irreversible binding or those which require activation prior to binding. A good correlation between rate of absorption, plasma level and urinary excretion can usually be established and such correlations can be used to establish an approximation of tissue storage. Pharmacokinetic studies may indicate that additional substituent group(s) have changed the biotransformation mechanism, tissue storage and elimination. Such studies on 3,3′-dichlorobenzidine showed that only 1% of the administered dose was eliminated via the urinary pathway in 15 days and tissue concentration could not account for the balance. However, chemical levels in body fat stores were not measured. Thus it would appear that chlorination of benzidine may have changed body storage and resulted in an aromatic amine behaving like an organochlorine compound. A similar situation has been observed with diisopropyl fluorophosphate where the primary target organ is acetylcholine enterase and the secondary one is the brain neurotoxic esterase. The result of enzyme inhibition is a peripheral neuropathy with demyelination followed by loss of function in the limbs similar to that originally reported from ingestion of o-tricresylphosphate. Pharmacokinetic studies can determine the degree and time course of cholinesterase inhibition and recovery and *in vitro* studies can give similar information on chicken brain neurotoxic esterase, but only nerve condition studies can give information on developing delayed neurotoxicity in humans prior to clinical manifestation of the disease. In this instance, animal studies can act as a preventative of human disease. All newly developed organophosphate pesticides should be studied in this manner prior to introduction into the environment. Another environmental contaminant which could be subjected to a pharmacokinetic study is vinyl chloride. Working area and workers could be studied under almost ideal conditions where quantitative atmospheric contamination and blood and urine concentrations might give a better insight into absorption and excretion. Animal studies would enable definitive correlations to be established between animal and human responses.

PHYSICAL STATES

In any study of a new or old environmental chemical the animals are rigorously checked and maintained, whereas humans exposed to such chemicals usually suffer from various degrees of physical impairment, i.e., hypertension, diabetes, etc. The use of healthy animals under such circumstances can result in data which cannot be extrapolated to man. It is imperative that animal studies be initiated to ascertain the effects of such impairments on overall responses. In addition, exposures to more than one environmental contaminant, particularly those which affect different body systems, could generate data which would have greater application to human responses. Studies with aged animals could also bring into focus the possible responses to be expected in aging humans, particularly the influence of lower levels on environmental contamination in situations where biotransformation enzyme activities have decreased and there is a partial impairment in excretory function.

THE ASSESSMENT OF EXPOSURE AND ITS PREVENTION

In any extrapolation of animal data to human experience, it is essential that the degree of actual human response be assessed in terms of available animal information concerning time-concentration of the chemical involved. Where air and water analyses are done on a continuing basis, the degree of human exposure is readily obtainable. A similar situation occurs in occupational exposures where continuous monitoring has been instituted, as in vinyl chloride plants. Such monitoring has the added advantage of determining those instances in which "peaking" occurs, resulting in a far higher concentration of chemical than normally is present in the ambient atmosphere. Equipment leaks which gradually increase the toxicant concentration can also be detected. Animal data are not available because research has not covered this area although episodes have been recorded where humans have been subjected to such exposures.

Probably the largest area of environmental contamination to which humans are exposed is local and area wide air pollution related to the operation of the internal combustion engine and/or various industries such as steel making, power generation, etc. A large number of the chemical entities are gaseous (SO_2, SO_3, O_3, NO_x, CO) and particulate (benzpyrene, fly ash, etc.) and they are monitored on a continuing basis and reported as daily pollution indices. Here again it was human exposure with its pulmonary effects and eye irritation which stimulated animal research to determine the effects produced by known concentrations of gaseous pollutants, the influence of particulates on the response and, finally, the effects of combinations of pollutants or UV irradiated automobile exhaust on both eye irritation and pulmonary function. The animal data closely paralleled that obtained on humans. "Normal" humans may or may not respond to low levels of air pollution but physically impaired humans (asthmatics, cardio-pulmonary case, etc.) are readily affected. Morbidity and mortality statistics indicate the highest levels of adverse responses occur the week after acute exposures as in the London air pollution episode of 1952. Ambient temperature can also complicate the situation as was observed in Los Angeles in 1954 where unseasonally high ambient temperatures increased the death rate in nursing homes having cardio-pulmonary patients.

Occupational exposure to chemicals can be controlled and decreased by good industrial hygienic practices, respirators, protective clothing and closed systems. The use of action levels of a given chemical in ambient air causing monitoring of employees in the area should assist in reducing overall occupational in urinary-excreted, naturally present chemicals and assist in preventing new vinyl chloride-like episodes before they become complete disasters. Also monitoring employees for changes in body fluids, changes in urinary-excreted, naturally present chemicals and radiographic tissue changes would also be of assistance. Examples include Δ-aminolevulinic acid excretion or aminolevulinic synthetase in blood from lead exposure and Raynaud's syndrome, scleroderma and acroosteolysis from vinyl chloride exposure. Warnings of such changes would indicate action to prevent more disastrous events such as encephalophy or cancer. However, a rational approach must be employed, otherwise economic dislocation will ensue or the suggested cure may be worse than the situation it is set up to correct.

Another area for consideration in both prevention and anticipation of future episodes involving environmental chemicals is the existing literature covering experimental animals and clinical research data. Reviews of existing material should indicate areas requiring additional work for clarifying possible problems. Epidemiology of selected populations could indicate areas of concern and suggest remedies.

CONCLUSIONS

The problems associated with the extrapolation of animal data to human responses have been discussed with the view to making such extrapolations more accurate and areas of research have been suggested to assist in the process. The multiplicity of the systems involved make the problem difficult but not insurmountable. Cooperation of the scientists of the USA and the USSR is essential if progress is to be made and human life improved through carefully conducted environmental research.

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DETERMINATION OF CRITERIA OF HARMLESS CHEMICAL EFFECTS ON THE HUMAN ORGANISM AND THE PROBLEM OF PERMISSIBLE LOADING

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Intensive industrialization and urbanization have to an ever greater degree led to the pollution of the biosphere with chemical compounds which to a greater or lesser extent can have a negative effect on the organism of man, population, ecosystem and the biosphere as a whole.

Under these conditions it is particularly important to define the criteria and methods permitting the objective exposure of their unfavorable impact on man and various biological systems for the purpose of developing both collective intergovernmental as well as regional (within the framework of individual countries and regions) safety measures as well as measures to avert the accumulation of dangerous levels of toxic substances in the biosphere. Objectively assessing the growth of environmental pollution, we believe it to be groundless to view the demands of certain researchers of the possibility of going back to the so-called "natural conditions." Without mentioning the fact that such a "return" would deprive us of the possibility of enjoying the benefits of civilization which mankind has acquired in the process of its development, we know that even the "natural conditions" are not always a guarantee for the health of man. For example, an area with an imbalance in the content of certain microelements (iodine, fluorine and other substances), naturally heightened radioactive background and other natural conditions, have an unfavorable impact on health.

We also cannot agree with those who strive to orient themselves to the technical possibilities existing in each specific case.

In our country an extremely realistic concept has been developed in this regard. It was clearly formulated by Leonid Il'ich Brezhnev, the general secretary of the CC CPSU, in his report to the 24th party congress. He stated: "In adopting measures to accelerate scientific and technical progress it is necessary to do everything so that it would be combined with an economic attitude toward natural resources, and would not serve as a source of dangerous air and water pollution and depletion of the earth." Increasing pollution of the environment cannot be viewed as an inevitable result of the scientific and technical revolution. In the Soviet Union, as in other countries there are many examples vividly illustrating the possibility of developing wasteless technology, utilizing industrial waste which previously was discharged into reservoirs, air and food products.

The basis of these measures in the USSR is formed by scientifically determined hygienic requirements and regulations assuring optimum relations of man and the population as a whole with the environment.

In principle, without excluding the possibility of developing ecological norms or loads as a whole or for individual systems of the biosphere in the USSR primarily scientific criteria of individual factors of the environment (water, air, air in the workers' zone, food and others) were worked out guaranteeing the optimum conditions for man's life and work.

In a paper at the preceding symposium devoted to the "Comprehensive Analysis of the Environment" (in 1974 in Tbilisi, USSR) we dwelt on the concept of the hygienic norming of toxic substances and other factors of the environment accepted in our country.

In determining the criteria of safety — the maximum permissible concentrations (MPC) (or what is synonymous — the maximum permissible loads) of toxic substances, we proceeded from the understanding that the MPC must not disturb the requisite physiological balance between the organism and the environment or during prolonged impact assure the maintenance of the complete health of the population and favorable sanitary conditions of its life.

The theoretical base when establishing the hygienic norms is the dialectical-materialistic teaching of the threshold of all types of actions of toxins (including the blastomogenic and others). Therefore, at the basis of the health standard setting (when establishing the MPC) along with a study of the limiting indices for the environment lies the principle of defining the threshold of damaging impact. As the threshold we accept that minimum concentration or dose of the substance in the environment under the effects of which the organism changes with certain conditions of its injection, which exceed the bounds of physiologically adaptive reactions and a temporarily compensating pathology sets in.

The objective evaluation of the biological threat of chemical compounds is based on the results of experimental studies conducted on various types of laboratory animals. For the purpose of unification of the methods employed to elicit the minimum effects of the biological action of the chemical compounds, a plan has been worked out for carrying out studies, the selection of laboratory animals, types of interactions of the organism and pollutants under study, the sequence for the conduct of acute and subacute experiments and indices required for eliciting the minimum effects, consideration of the experimental toxicological and hygienic studies, and so on. The single basis for all studies promoted the obtaining and accumulation of comparable data. This also with time assures the possibility of reaching theoretical conclusions permitting a more precise forecast of the results and nature of the effect of the substance.

Despite certain differences in the methodological approach in calculating the damage from the actions of the chemical compounds on the organism in various media (air in a workers' zone, air, water in a reservoir, in food and others) the principles and methods for calculating the minimum effects of the pollutants are alike in many ways. All of them envisage a three-stage experimental study on the animals: 1st stage, acute experiments; 2nd stage, intermediate (repeated) experiments (1 to 2 months); and the 3rd stage, chronic (3 to 6 months and longer) experiments.

The studies employ adequate, highly sensitive physiological, biochemical, toxicological and other methods. Relying on the arsenal of the achievements of current biology and medicine, studies are conducted on the nature of impact of the chemical compounds on the organism of the test animals as a whole and on their individual organs and systems. Among these particular attention is devoted to the central nervous system (including a study of the bioelectric mosaic of the brain and the subcortical formations), the cardiovascular system, enzyme spectrum and, in particular, the organospecific enzymes. The use of varied methods and tests permits the discovery of the slightest and earliest changes in the functional state of the organism short of the threshold harmful action of the substance.

Along with this studies are conducted with volunteers as well as epidemiological studies, observations of people under natural conditions. It should be noted that a specially conducted study of the question of the possibility of a "transmission" to man of data obtained in experiments with animals showed that the experimentally substantiated values, as a rule, protect man to a sufficient degree from the unfavorable effects of chemical compounds.

In setting up the experiments significant value was assigned to elicit primary effects of the actions of toxic substances (in acute and subacute experiments) and particular attention was devoted to a determination of the cumulative properties. By these properties we mean an acceleration of the action of the toxin during its repeated intake by the organism as a result of the accumulation of the active toxic substance (material cumulation) or the summation of trace reactions resulting from the impact of the substance (functional cumulation).

The cumulative action of the chemical compounds is conditioned by the combination of the processes of absorption, distribution, accumulation and conversion of toxins entering the organism.

The value of the introduced dose and the time factor play a significant role in the evaluation of the cumulative effect.

The state of accumulation includes the combination of the elements of "breakdown" and adaptive stress of the functions of the organism.

Moreover, we differentiate the stages of true physiological adaptation to changed conditions of the external medium from the stage of latent compensatory pathology. In order to differentiate these stages we normally employ so-called functional load tests (alcohol load, hexenal sleep, hypothermia, determination of working capacity, time of restoration to straight line movement following rotation in a centrifuge, electronic action on the cerebral cortex).

In addition to adaptation there may be another phenomenon which is the state of acclimatization. At the same time the organism develops resistance, there is a heightened resistance to the action of the toxin, the absence or decrease of shifts in the state of the organism. According to present day concepts the state of acclimatization must be evaluated as the first phase of intoxication.

Questions of accumulation, adaptation and acclimatization are of great importance in hygienic norm setting since the definition of these effects permits a more precise selection of the coefficient of reserves when establishing the MPC.

In our report we have dwelt in detail on studies to find the primary effects and cumulation because at the present time a plan is being worked out at the Moscow Institute of Hygiene im. F. F. Erisman for an accelerated joint experiment to establish orientation values for MPC in the atmosphere, reservoir water, in the air of a workers' zone and food products.

Moreover, we devote particular attention to studying the phases of the reaction, their direction, definition of adaptation, acclimatization and cumulation. Obtaining the orientation values of the MPC plays an important role in determining the forecast of the biological action of new chemical substances in our environment.

The multiplicity of chemical compounds circulating in the environment predetermines the inevitability of the combined, that is, sum of substances and complex action of them on the organism of man (during inhalation, perorally, through the skin).

The complexity of the evaluation of the mechanism of biological action of the mixture of chemical compounds depends on many factors. Integrally the effect can manifest itself as antagonistic, or synergetic or additive. This question was reported on by us in detail at the previous symposium (USSR, Tbilisi, 1974). At that time we remarked that the summary effect is observed most frequently. The degree of danger from the combined action of chemical compounds possessing the summary effect can be calculated by using a formula where the sum of the ratios of the true concentrations of chemical compounds to their MPC for example in atmospheric air must not exceed one.

The principle difference from the combined action is the complex effect as a result of the features of the biological effects with various ways for the substances to enter the organism. In this case the sequence of the intake of substances (peroral or inhalation) may be of great significance. Under the effect of chemical compounds in concentrations at the threshold level of chronic action, during the complex intake by the organism of substances perorally, or by inhaling, as well as in the majority of cases with the combined substances, we observe a summation of biological effects. Therefore, the total quantity of chemical compounds which can enter the organism of man from various media must not exceed the maximum permissible dose for man.

In recent years much attention has been devoted to a study of individual consequences of contact by man with chemical substances to set hygienic norms. Therefore, during the health standard setting of toxic substances methods are employed characterizing chromosome and mutations which according to the data of our institute can appear as early as in the first generation. Disturbance of the genetic balance represents a grave danger.

Of particular interest is the influence of chemical substances on the generative functions of the organism (embryo-gonadotoxic and teratogenic effects) and the appearance of blastomogenic activity. Remote consequences can also affect changes in the cardio-vascular system. In order to find these consequences specific methodological methods of investigation are developed. For example, in evaluating the cancerogenic activity of substances use is made of the transplantation method of investigation.

The hygienic norms (MPC) established in this manner on the basis of comprehensive studies, at the level of inactive subthreshold values are confirmed by state agencies and then become obligatory for all institutions, enterprises, design organizations as well as for current sanitary and preventive control. In this manner a reliable system is set up to protect the population against the harmful effects of chemical compounds entering the environment. The MPC permits the establishment of a biologically justified standard of man's environment and also promotes the creation of favorable sanitary conditions for a healthy existence inasmuch as during health standard setting it is necessary to take into consideration the effect of the substances on the state of the environment. For example, smell of water, turbidity, color, self-purification in the reservoir and others.

Our methods have been recognized internationally. For example, the MPC developed in the USSR for water in reservoirs in areas where water is used by the population are published by WHO. At the same time we know that in certain countries the basis of regulations for the quality of the environment is formed by the principle of maximum acceptable concentrations or concepts of acceptable risk which we do not share.

In recent years the attention of investigators has been drawn to the problem of the establishment of permissible loads in the broadest sense of the word, beginning with the individual biological systems and to the biosphere as a whole. This question is of great theoretical interest; however, in developing permissible loads for man it must be based on the principle of health standard setting. Along with the extensive positive experience from the effort to establish maximum permissible doses (loads) at the present time there naturally arise a number of important new questions from the point of view of theory and practice.

For example, in determining the MPC (or maximum permissible loads) of chemical compounds importance is ascribed to the discovery of such quantitative indices as the value of accumulation, removal of substances from the organism, results of conversions and others. For this purpose we now employ so-called exposition methods (exposition tests). As experimental research has shown they permit the establishment of a specific correlation between the excretion of certain substances (lead, mercury, manganese) with urine and the level of their concentrations in the inhaled air, however, this correlation is disturbed when examining individuals. Apparently, the use of expository test samples for the purpose of setting the permissible loads requires further clarification including numerous epidemiological and clinical-laboratory examinations.

It would be logical as well to have at hand precise data on the values of the toxic substances which can "settle" in the organism, their distribution and dynamics of accumulation depending on the dose, time of action and other conditions.

Of vast importance as well is the definition of the "critical" organ where the basic portion of the toxin accumulates, or where it is absent.

Of particular significance is the study of the intermittent action of the chemical compounds during complex and combined entry into the organism.

In summing up, the results state that the establishment of MPC (loads) on the organism of man requires a necessary calculation of the threshold, cumulative properties of the substances, adaptive abilities of the organism, the possibility of combined and complex action, remote results as well as substance parameters which, in the organism or critical organ, do not over a period of many years change the state of health and do not have a negative effect following the impact.

PROJECTED HEALTH IMPLICATIONS OF MAJOR AUTOMOTIVE EMISSIONS

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The health hazard associated with a given environmental pollutant depends on three basic parameters:

—First is the concentration level of the pollutant to which a given population is exposed. Accurately determining the concentration has always been difficult because of limitations in measurement technology, different chemical forms of the pollutant in the atmosphere, and the uncertainty in relating the pollutant level in air to the actual dose a given individual would receive.

—The second parameter is the range of susceptibility of a given population. For example, we know that patients with heart disease are more susceptible to the effects of small amounts of carbon monoxide than are healthy subjects. From the concept of the range of susceptibility, we can designate the population at risk to exposure to a given pollutant.

—The third parameter which needs to be considered in assessing the health hazard of an environmental pollutant is the spectrum of response which refers to the various ways an individual can manifest the effects of environmental stress. The spectrum of response can range from the mildest, such as slight biological changes of uncertain significance, to the most severe, that is, mortality.

These three dimensions make up an exposure-response matrix which can provide a tool for objectively determining human health effects from environmental pollutants. The question we want to answer is "How many individuals in each category of our population are subjected to what levels of risk for a given range of pollutant concentration?"

Automotive emissions have long been recognized as having a significant impact on the air quality and subsequently to health and welfare of the United States. In assessing the projected health implications of major automotive emissions including carbon monoxide, photochemical oxidants and their precursors, and oxides of nitrogen, we must take into account the parameters of the exposure-response matrix which have been described. It is possible to develop a damage function for each of those pollutants which relate per year health consequences to incremental levels of air pollutant exposure using a total population basis. In conjunction with the damage function, projected pollutant concentration, and the projected population for a given area, we can estimate the human health consequences which may be expected to result from the implementation of various mobile source control strategies. This concept can be applied on an individual basis to those pollutants associated with mobile source emissions.

CARBON MONOXIDE

The current U.S. ambient air quality standard for CO is 10 mg/m^3 for an 8 hour average and 40 mg/m^3 for a 1 hour average [1]. Carbon monoxide exerts its adverse physiologic influence by interfering with oxygen transport to the cellular level. This occurs due to formation of carboxyhemoglobin (COHb) by combination of inhaled CO with the hemoglobin which ordinarily carries oxygen.

The damage function, shown in Figure 1, relates excess person hours of disability, that is, chest pain and decreased activity in people with stable coronary artery disease, to incremental ambient levels of carbon monoxide exposure. It was derived from the data of Anderson et al. [2] which related the effect of low-level CO exposure in persons with stable coronary artery disease to the duration of chest pain. Regression lines for excess disability assuming various carboxyhemoglobin threshold levels were developed and incorporated into an estimate of the general population at risk. The ambient levels were expressed as the annual geometric mean of the maximum daily eight-hour average for each of the three standard geometric deviations. The annual geometric means varied from 2 to 10 mg/m^3 and the three standard geometric deviations provided for each mean were 1.3, 1.5 and 1.7.

We may now apply the damage function to a given area in conjunction with a projected population estimate and an estimate of ambient air quality. Let us use San Francisco as an example. The projected population of San Francisco in 1980 is 3.4 million and in the year 2000 it is 4.2 million people [3].

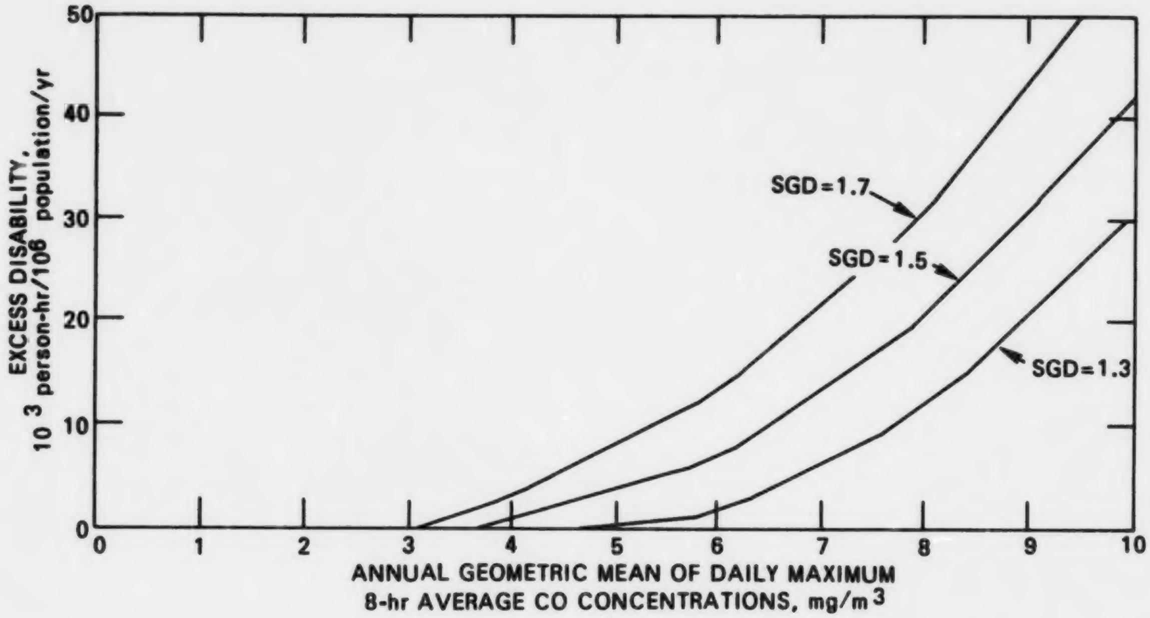

Figure 1. Damage function for exposure to carbon monoxide: excess disability versus CO concentration.

The projected air quality for carbon monoxide is based on a number of assumptions:

- —That the average lifetime of an automobile in the U.S. will be 13 years.
- —That for the air quality level of carbon monoxide, a growth of one percent compounded annually can be expected from automobiles. This reflects the fact that carbon monoxide is a localized problem where traffic density is already high and that growth in those areas will not be as great as for the broader metropolitan areas.
- —That new emission standards are assumed to take effect in 1978.
- —That the deterioration rate of control devices for mobile sources is reduced from that presently occurring by assuming that inspection and maintenance plans will be in operation nationwide.

For a vehicle emissions standard of 25 gm of CO/mile, we can calculate an average air quality level of 9 mg/m^3 in both 1980 and 2000 [4]. If we assume a standard geometric deviation of 1.5, 100,000 person-hours will be lost due to excess disability in 1980 and 1.25 million person-hours in 2000.

On the other hand, for a vehicle emission standard of 9 gm/mile, the CO level in San Francisco will be 9 mg/m^3 in 1980 and 4.6 mg/m^3 in 2000 [4]. This means that 100,000 person-hours will be lost in 1980 but only 10,500 hours in 2000, a decrease of 99% over the 25 gm/mile emission standard.

PHOTOCHEMICAL OXIDANTS

The present U.S. National Primary Standard for photochemical oxidants is 160 μg/m^3 maximum one hour concentration not to be exceeded more than once per year [1]. Compliance with this Ambient Air Quality Standard (AAQS) is sought by emission control of hydrocarbons which are oxidant precursors, rather than control of oxidants themselves.

The original evidence for the ambient standard in humans was based on increased illness including aggravation of asthma and chronic lung disease, irritation of the respiratory tract in healthy adults, decreased visual acuity, increased eye irritation, and changes in heart and lung function in healthy subjects.

Damage functions at three geometric standard deviations are shown in Figure 2 relating the annual geometric mean of the daily maximum 1 hour concentration to excess chest discomfort. It was derived from data developed from the Los Angeles Student Nurse Study carried out by Hammer et al. [5]. Applying the same assumptions as in the case for carbon monoxide but assuming a growth of 3% compounded annually and a standard geometric deviation of 2.2 we can project the health consequences of automobile emission control strategies.

Let us take the Portland, Oregon area as an example. For an emission standard of 2 gm/mile,

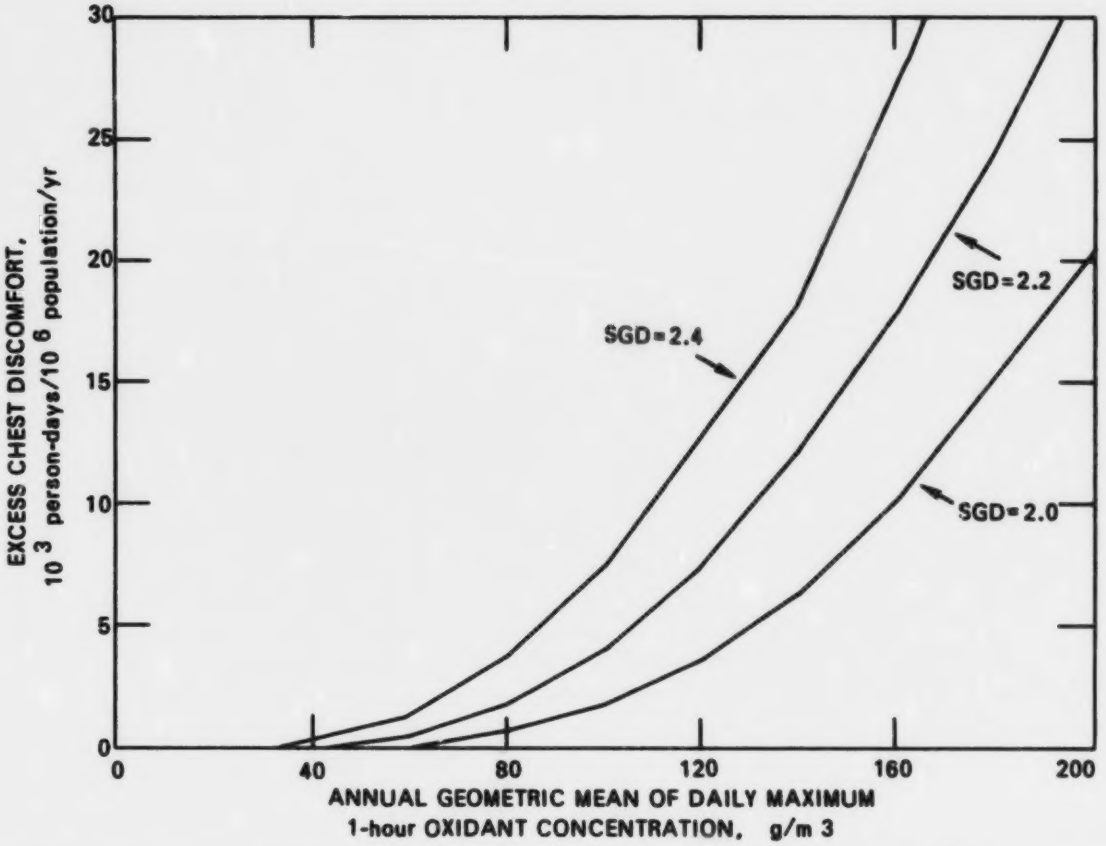

Figure 2. Damage function for exposure to oxidants: excess chest discomfort versus oxidant concentration.

the ambient air quality oxidant concentrations will be 176 μg/m³ in 1980 and 157 μg/m³ in 2000 [4]. With a projected population value of 1.1 million people in 1980 [3], 26,000 person days of excess chest discomfort can be expected. With a population of 1.4 million in the year 2000 [3], 21,000 person days will be affected.

For a lower oxidant standard of 0.4 gm/mile, 17,000 person days of excess chest discomfort can be expected in 1980, which is 35% less than with a 2 gm/mile standard. For the year 2000, 5600 person days would be affected, which is 70% less than with the 2 gm/mile standard.

Similar calculations can be made using a damage function shown in Figure 3 which relates excess headache and eye discomfort to the annual geometric mean of the maximum one hour oxidant concentration.

NITROGEN DIOXIDE

The current primary and secondary AAQS for NO_2 is 100 μg/m³ annual arithmetic mean [1]. The current AAQS was based largely on a set of studies conducted in Chattanooga, Tennessee [6]. These, often referred to as the Chattanooga School Children Studies, afforded an opportunity to assess the influence of NO_2 on acute respiratory disease experience in populations.

The damage function shown in Figure 4 related excess attacks of lower respiratory disease in children and corresponding excess days of restricted activity to incremental ambient levels of nitrogen dioxide exposure. It was derived from the data obtained from three communities in the Chattanooga study [6] which represented high, intermediate, and low exposure levels to NO_2. Using an intermediate exposure level, a linear function was developed and incorporated in an estimate of the population. For each occurrence of lower respiratory disease, a constant of 2.66 days of restricted activity was used.

As in the case of the other damage functions shown, this damage function clearly shows excess lower respiratory diseases occurring at levels below the current annual standard for nitrogen dioxide of

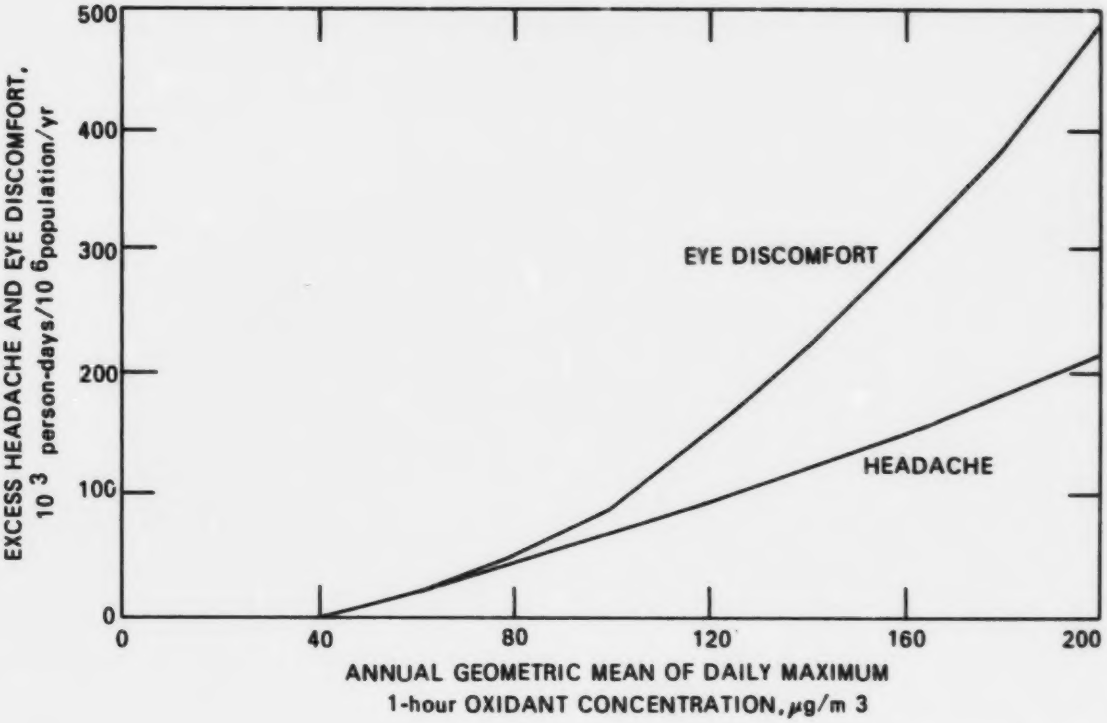

Figure 3. Damage function for exposure to oxidants: excess headache and eye discomfort versus oxidant concentration.

100 $\mu g/m^3$ [1] as an annual arithmetic average. While the annual standard is felt to be adequate on an annual basis, that human health consequences have been calculated at lower levels suggests this standard is probably not sufficient. Recent data obtained from laboratory studies suggest human health consequences may occur under peak exposure conditions for short durations. These peak exposure effects are probably reflected in this damage function. EPA is currently investigating this question, and the possible need for a short term National Ambient Air Quality standard for nitrogen dioxide.

Using the damage function to assess the effect of control strategies, we find in St. Louis for example, that implementing a NO_2 standard of 3.1 gm/mile will result in 416,000 excess days of restricted activity in 1980 and 532,000 days in 2000. But a standard of 0.4 gm/mile will result in 390,000 days in 2000, a reduction of 6% — but only 280,000 days in 2000, or a decrease of 48% from the 3.1 gm/mile standard.

CONCLUSIONS

Damage functions can provide us with tools for estimating exposure-response relationships associated with automotive control strategies. It is recognized that these functions are based on a number of assumptions and approximations and were derived from a limited health data base. They do, however, give us an estimate of the projected human health risk which can be expected. We are sure that as more results from animal toxicology, clinical and population studies become available, we will be able to further refine damage functions.

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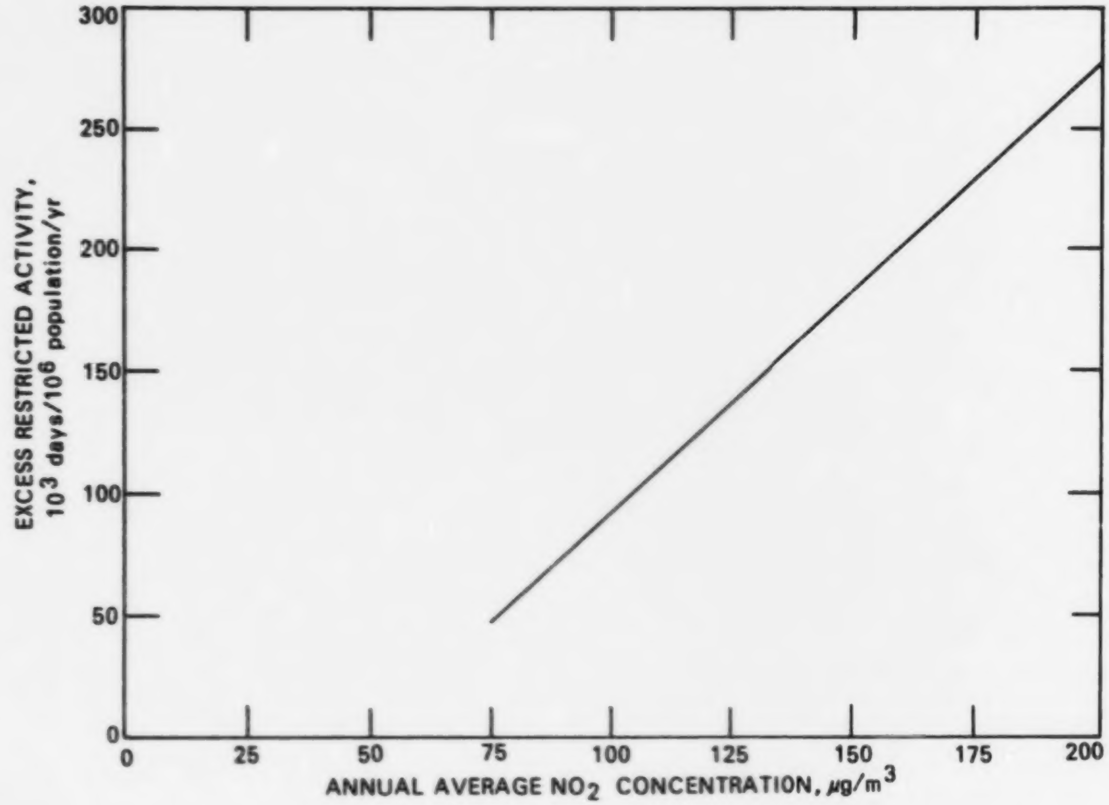

Figure 4. Damage function for exposure to nitrogen dioxide: excess restricted activity in children with lower respiratory disease versus NO_2 concentration.

HYGIENIC CRITERIA OF MAXIMUM PERMISSIBLE LOAD

G. I. SIDORENKO and M. A. PINIGIN

As we know, the current development of productive forces is in many instances accompanied by qualitative and quantitative changes in the state of the environment and in particular in its chemical composition. A redistribution of chemical elements, is taking place on earth as a result of man's activity; biogeochemical provinces are being disturbed which were formed in nature; there is an increase in the pollution of air, water, soil and of food products by various chemical agents. For example, in a number of countries the pollution of air in the cities has reached a point where it presents a threat to health and in some situations to the lives of people. Consequently, among the many aspects of the problem dealing with the environment much importance is ascribed to the question of protecting the life and health of man, thereby pointing to the necessity of evaluating the danger of chemical pollution.

The hygienic assessment of the danger of chemical pollution of the environment includes two aspects, one of which is tied in with the substantiation of the criteria of the degree of pollution (hygienic norms) and the other with the use of these criteria in practice to control the quality of the environment.

HYGIENIC NORMS OF THE PERMISSIBLE CONTENT OF HARMFUL SUBSTANCES IN THE ENVIRONMENT

The hygienic norms for the permissible content of harmful substances are the maximum permissible concentration (MPC) for various media of the environment (air, water, soil, food products).

The MPC include concentrations which do not directly or indirectly affect man and his progeny, do not reduce his ability to work, or his state of health as well as the sanitary-living conditions of the lives of people.

The norm setting of the permissible content of chemical factors in the environment is based on the concept of the presence of thresholds in action, although the threshold values themselves (concentrations) are relative and depend on many causes, both physical (aggregate state of the substance, medium, regime duration of intake and so forth) and biological (physiological state of the organism, age, methods of intake and others).

Threshold concentrations are generally recognized as those minimum concentrations which under certain conditions are capable of harming the organism of man or the environment. Inasmuch as the harmful effects of the chemical agents on the organism and the environment are varied, use has to be made of the limiting index in establishing the hygienic norms, (V. A. Ryazanov, 1952; S. N. Cherkinskiy, 1971; G. I. Sidorenko, M. A. Pinigin, 1971, et al.).* In accordance with this principle norm setting is carried out for the most sensitive index. For example, if odor of a substance is noticeable with concentrations which do not have a harmful effect on man or the environment, then the norm setting for atmospheric pollution is conducted taking into consideration the threshold of the olfactory senses. If the substance has a damaging effect on the environment with lesser concentrations than on the organism of man, the process of norm setting proceeds from the threshold of action of that substance on the environment. In designating the MPC of chemical substances in the water of reservoirs and having established the threshold and inactive concentrations of the effect on the organoleptic properties of water (odor, taste, color and turbidity) and on the general sanitary regime of the reservoirs (change in the biochemical processes of the mineralization of organic substances) as well as the toxic effect on the organism of man as a limiting indication, we accept that for which the threshold and inactive concentrations are the smallest.

A characteristic of hygienic norm setting of the permissible contents of harmful substances in the environment is also conditioned by the extreme variability of their concentrations in time and space, which is linked with the variety of their causes. Most significant is the variability of the concentrations of atmospheric pollution. Therefore, the concentrations calculated for the same point but with different degrees of averaging during the selection of test samples have significant differences. Then, the nature of the concentrations in the environment can be correct only when there is a simultaneous degree of averaging of the analytical data in time: average hourly, average daily, average monthly, average yearly, and so forth. Consequently, the norm values of the MPC must be, by degree of their averaging, different in time. Inasmuch as the effect of the harmful substance depends both on its concentration and on the duration of the contact, the concentration which is harmless during a brief inhalation may become dangerous with a more prolonged inhalation. Substances which have generally toxic effects with an expressed cumulative effect have the norms set by following average concentrations over a prolonged period.

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*No references accompany this paper.

As a result of the significant variability in the content of substances in the environment, the average concentration over a prolonged period cannot guarantee the fact that the content of the substance will not exceed the threshold of acute action for a brief span of time. Therefore, in addition to the average concentrations, it is necessary to indicate the boundaries of their vacillations, that is the maximum permissible monetary or "peak" concentration. This first of all must refer to substances with expressed irritant effect on the mucosa and substances with a strong odor since the perception of the odor or of a sense of the irritation of the mucosa does not require prolonged exposure (V. A. Ryazanov, 1952).

In accordance with basic tenets of hygienic norm setting for the permissible content of harmful substances in the environment, the state sanitary legislation of the USSR, at the present time, includes norms for over 450 substances in the water of reservoirs and over 160 substances in atmospheric air, during their isolated impact on the organism.

However, under present conditions each object in the environment (air, water, food products) can be contaminated simultaneously by various chemical compounds, resulting in the need to study their combined actions.

The evaluation of the nature of the combined action is based on the comparison of the effect produced by a mixture of the substances with the effect reached during the isolated action by components of the mixture. Therefore, usually having established the threshold concentrations for the isolated action of the substances, the mixtures are made up including the individual components in parts from the established thresholds calculated so that the sum of these parts is smaller, equal to or greater than a unit. If the mixture results in an effect equal to the threshold during isolated action and its concentration expressed in parts of the individual thresholds is equal to a unit, then the nature of the combined action is assessed as a manifestation of additivity (summation). The finding of the threshold effect with a concentration of the mixture less than a unit points to the synergism effect during combined action and with summary concentrations larger than a unit points to manifestations of antagonism.

As shown by the process of norm setting, at the level of small concentrations found in the environment, many substances during their combined action render an impact by the type of summation effect (I. V. Sanotskiy, 1969; M. I. Gusev, 1970; G. I. Sidorenko, et al., 1973; and others). In this case the permissible level of the content of several substances, with their combined presence in a specific medium, is that where the sum of concentrations expressed in parts of the MPC of the substance equals a unit. In the event of antagonism the sum may be larger than a unit and in the case of synergism less than a unit.

Under present conditions man may be subjected to the unfavorable actions of not only various combinations of chemical substances simultaneously appearing from some object in the environment but also the action of one substance from several objects (air, water, food). The impact of the substance entering the organism simultaneously by several routes is called complex.

Existing methods for establishing hygienic norms of a substance separately for atmospheric air, air at production sites, water in reservoirs, and in food products do not take into consideration the possibility of its simultaneous entry into the organism. This determines the need for developing approaches to complex (single) norm setting for chemical compounds in the environment.

In view of the differences in the principles and criteria for establishing the MPC of harmful substances in various media we at the present stage are dealing with development of approaches for single norm setting for those substances the permissible content of which is limited by their resorptive, i.e. toxic action. Proposals aimed at the solution of the question of complex norm setting are being examined in this particular plan (Ye. I. Spynu, et al., 1971; A. I. Korbakova, et al., 1971; G. I. Sidorenko, M. A. Pinigin, 1971; and others).

Probably the courses for resolving the methodological questions of the evaluation of danger of chemical substances during their complex entry into the organism can vary. However, the determining factor in developing the approaches to single hygienic norm setting is the calculation of the biological equivalency (isoeffectiveness) of doses and concentrations of harmful substances entering the organism by different routes and in various regimes.

Along with an evaluation of the environment for the level of pollution certain authors consider the biological "integral" established with the aid of highly sensitive biochemical and enzymological tests of exposition to be an important index of the total action of the substance (I. D. Gadaskina, V. A. Filov, 1971, et al.).

Efforts, which have been undertaken to further expand the bases for hygienic norm setting of chemical factors, present new tasks in light of the further integration of criteria of the quality of the environment. In fact, in solving questions of the evaluation of combined and complex impact individually, one must not forget that these actions render their influence on man simultaneously; that is, at a specific moment each medium may contain several substances, while a number of substances may be present not in one certain substance alone but in other media. For the purpose of calculating and evaluating this integral action it probably is not possible to disagree with the suggestion of establishing a maximum permissible chemical load.

Undoubtedly, the definition of the concept of the maximum permissible load (MPL) must in principle be the same as the definition of the MPC, that is, the MPL is the maximum content of harmful substances in the environment which does not result in direct or indirect unfavorable effects on the organism of man and his progeny, does not deteriorate the hygienic and daily conditions of life. However to measure the maximum permissible load it is not really possible to use the measures employed for the MPC (mg/m^3, mg/1 and so forth). Apparently, the most satisfactory measure of the MPC can be expressed in relative terms, for example, in parts of the MPC of the substances present in the environment taking into consideration the nature of the combined and complex action of these substances.

In both instances, in order to calculate their nature, as previously mentioned, it is particularly important to use biologically equivalent (isoeffective) concentrations.

The calculation of biological equivalence of the concentration of a substance can be based on the use of quantitative dependences and in particular on "dose-effect" and "dose-time." In the case of using, for purposes of evaluation of the complex action, the "dose (concentration)-time" complex as the isoeffective concentrations, we also employ those which evoke similar effects over the same interval of time.

In connection with the importance of determining the dependences "dose-effect" and "dose-time" for quantitative evaluation of the nature of combined and complex actions of the chemical agents we present below the empirical values for the expression of these dependences.

THE DEPENDENCE CURVES OF THE "DOSE-EFFECT" AND "TIME-EFFECT" AND THEIR USE IN THE SOLUTION OF QUESTIONS OF THE MPL

The most typical dependence curves between the toxic dose and the reaction are the S-shaped curves which on the punctured grid are approximated by the straight lines. Unfortunately, we must note the fact that as a result of the complexity of setting up the chronic experiments, the dependence curves of the "dose-effect" at low concentrations are not as a rule established. In connection with this it is, at the present time, difficult to judge the nature of the "dose-effect" curves at low concentrations during prolonged exposure. An even more complex task is the establishment of similar curves on the basis of epidemiological studies of the interaction of the health of the population with the degree of environmental pollution. However, establishment of the nature of the dependence "dose-effect" curves at the level of low concentrations represents one of the most important aspects in the development of criteria in calculating the permissible levels of the chemical loads.

As long as the MPL according to definition is found below the levels of the threshold of action of the chemical compounds it is necessary to use, in the evaluation of the nature of the combined and complex action of the subthreshold levels of concentration. *(sic)* It is theoretically possible, that in the zone of subthreshold concentrations one can find the dependence of the "dose-effect" in the zone of the prethreshold concentrations as well. However, at subthreshold levels a direct measurement of the effects is impossible, therefore the "dose-effect" can be represented in the form of the dependence curve of the degree of intensity of the defensive-adaptive mechanisms from the level of threshold concentrations. This can be shown with the help of functional loads. Unfortunately, similar data are in practice not available. In connection with this an important task for defining the MPL calls for an ellucidation of the dependences of the "dose-effect" curves at the level of the subthreshold (or MP) concentrations.

In order to calculate the MPL, as previously noted, we can employ the "dose (concentration)-time" dependence.

Studies conducted at the Institute im. A. N. Sysin of the USSR Academy of Medical Sciences show that during uninterrupted inhalation of the substances the "concentration-time" dependence both during onset of acute toxic effects (marginal situation and death of the animals) and the physiological and biochemical shifts has the nature of a hyperbole, which on a grid with a logarithmic scale may be approximated with straight lines of various slopes.

In accordance with the equation of the straight line the empirical expression of the dependence "concentration-time" may be written in the general form:

$$\lg T = \lg T_0 - \operatorname{tg} L \times \lg C, \qquad (1)$$

where T is the time of the onset of the toxic effect during inhalation of the substance in a concentration of C; T_0 – time, equal to the accepted unit of time measurement, where concentration of substance C_0 results in the same effect; L is the angle of inclination (the concentration being plotted along the abscissa).

In changing the values according to the axes of the coordinates the equation of the dependence "time-concentration" can be shown as:

$$\lg C = \lg C_0 - \operatorname{tg} L \times \lg T \qquad (2)$$

From equation (2) we obtain an empirical formula of the dependence of the concentration of the substance in the air from the time of its uninterrupted inhalation:

$$C = \frac{C_0}{T^K} = C_0 \times T^{-K} \qquad (3)$$

where in addition to the known designations, K represents tgα (M. A. Pinigin, 1972).

Inasmuch as the "concentration-time" curves are integral reflections of the toxicodynamics of the substance as well as the state of the cumulation of the toxic effect and its compensation, the parameters of these curves (the angle of inclination or its tangents) permit judgment of the degree of danger (probability of unfavorable effect of the substance on the organism under actual conditions). Moreover, the greater the slope, the smaller the tangent of the angle, the more dangerous is the substance, since in this case a drop in the level of the concentration leads to an increase in comparison with the onset of this effect in other cases.

The logarithmic dependence of the time of onset of the toxic effects on the level of concentrations of the substance in the air permitted a classification of their threat according to the parameters of the "concentration-time" curve, Table 1.

Classification of the danger of substances as established according to parameters of the curve "concentration-time" during continuous inhalation as the comparison shows coincides satisfactorily with the classification established for these substances during labor hygiene with interrupted impact.

TABLE 1. CLASSIFICATION OF THE DANGER OF HARMFUL SUBSTANCES ACCORDING TO THE "CONCENTRATION-TIME" DEPENDENCE CURVE

Class of danger	Curve parameters		Increase in effect appearance time with a 10-fold reduction in substance concentration in air
	Slope	Tangent of inclination angle	
1st extremely dangerous	>155°	<0.475	for 3 times
2nd highly dangerous	155-137°	0.475-0.950	9 times
3rd moderately dangerous	137-125°	0.950-1.425	27 times
4th slightly dangerous	<125°	>1.425	>27 times

The possibility of obtaining "concentration-time" curves during inhalation and oral intake of substances permits a calculation of the biologically equivalent concentrations and on this basis a judgment of the nature of the combined and complex action. The evaluation of the nature of impact of the substance is carried out in accordance with the Finni formula. Here, the resultant isoeffective concentrations with the isolated impact of the substance are taken as 100% (or 1) while the concentration of the appropriate substances during combined or complex intake are expressed in parts of the isoeffective concentrations.

The parts obtained, expressed in percentages are added up. If the sum of parts of all components of the mixture approximates 100%, there is a summation, but if it is less, then there is synergism, and if it is over 100%, we have antagonism (M. A. Pinigin, 1974).

In accordance with the defined nature of the combined and complex impact of the substance we can calculate the MPL according to formulae: in the event of the summation effect:
MPL =

$$\frac{a_1}{x_1} + \frac{a_2}{x_2} + \,..\, \frac{a_n}{x_n} + \frac{b_1}{y_1} + \frac{b_2}{y_2} + \,....$$

$$\frac{b_n}{y_n} + \frac{c_1}{z_1} + \frac{c_2}{z_2} + \,...\, + \frac{c_n}{z_n} = 1$$

HYGIENIC ASSESSMENT OF THE ACTUAL LOAD OF CHEMICAL POLLUTION

The state of the environment is assessed following results of studies of the content of various chemical compounds based on a comparison with hygienic norms. In those instances, where the content of the harmful substances in the environment exceeds the permissible levels, we face the question of developing a short or long-range program for the purpose of cleaning up the specified environment. It is perfectly natural that the development of such programs must be based on a differentiated assessment of the danger of pollution. Moreover, like levels of MPC excesses for various substances do not point to the like danger of environmental pollution by these substances. The degree of danger of pollution is judged differently depending on the classification of danger of the chemical compound (I. P. Ulanova, M. A. Pinigin, 1974). In accordance with the classification of substances by degree of danger (probability of unfavorable effect on man under actual conditions) as adopted in the USSR, development continues on special nomograms for an assessment of the danger of pollution and particularly of air pollution (M. A. Pinigin, 1975). The nomograms represent isolines of the degree of danger of pollution for various multiplicity factors exceeding the MPC of chemical substances relating to various classes. This permits a "standardization" of the degree of danger from the actual pollution by substances of various classes for one class and on this basis a summary assessment of pollution as the index of pollution danter (M. A. Pinigin, R. M. Barkhudarov, I. K. Dibobes, 1975).

The index of the danger of pollution of one medium can be expressed in the form of a general formula:

$$\frac{\sum\limits_{m=1}^{C_N^2} \frac{(K_i+K_j)\, m}{2} \times n_m^{am}}{C_N^2} \qquad (1)$$

where: N is the quantity of the substance in the air;

C_N^2 is the number of all possible pairs of the substance;

$K_i+K_j/2$ is the average concentration of the * nth pair of substances the concentration of which is preliminarily standardized at** the threshold

n_m is the number of substances with a monotypic nature of combined action, (when all of the examined substances possess a monotypic nature of the combined action, then $n = N1$;)

A_m^{am} is the coefficient characterizing the effect of the combined action.

Naturally, in evaluating the actual load taking into consideration the intake of substances via water or other media the formula becomes more complex. However, the main complexity of the evaluation of the actual load lies in the fact that the coefficients describing the combined and complex action of substance remain in the majority of cases still unknown.

As further experiments are carried out, we unquestionably will be able to define more precisely the quantitative expression of the MPC and ways for applying it for the integral assessment of the chemical pollution of the environment which in turn will promote greater efficiency in raising the preventive and treatment measures in the sphere of protecting the environment from pollution.

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*Here the expression "concentration" means the brevity of exceeding the MPC.

**Standardization is carried out with consideration for the classification of the danger of the pollutants according to the nomograms.

RATIONALE FOR THE ASSESSMENT OF CARCINOGENIC RISKS

ROY E. ALBERT

BACKGROUND

Regulatory action against chemicals on the basis of carcinogen action has become an issue of considerable importance. There is evidence that a substantial amount of human cancer is caused by chemical and physical agents in the environment. Bioassay programs, currently testing hundreds of substances, are beginning to show that important industrial and agricultural chemicals are carcinogenic for animals and are, therefore, candidates for regulatory action. There is expectation that control of environmental carcinogens by Federal regulatory action will reduce the public health burden of cancer.

The first important regulatory step against carcinogens in the United States was the Delaney Clause of the Food and Drug Act which set a zero tolerance limit against carcinogenic food additives. However, the general application of such an idealized form of regulatory action is unrealistic because many carcinogens are too important to eliminate completely without intolerable socio-economic consequences. Consonant with this view, the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA), which is the enabling legislation for the control of health hazards from pesticides, requires a balancing of risks and benefits as the basis for regulatory decisions.

The Environmental Protection Agency (EPA) is developing procedures for analyzing health risks from suspect carcinogens as one component of the process of weighing risks and benefits. A draft of the Interim Guideline for Carcinogen Risk Assessment is attached as an Appendix to this paper.

There are two basic aspects to the evaluation of any risk: How likely is the risk to occur, and if it does occur, how bad are the consequences? Similarly, there are two fundamental questions to be answered by the risk assessment of a suspect carcinogen. How likely is the agent to be a human carcinogen? And if it is, how much cancer might be produced by the agent if allowed to go on unregulated? The best evidence that an agent is a human carcinogen is provided by adequate epidemiologic data backed by confirmatory animal tests. However, for practical purposes, the bulk of instances which require judgments about human carcinogenicity will come from animal studies.

The point of view taken in the EPA Guideline is that any evidence of tumorigenic activity in animals is a signal that the agent is a potential human carcinogen. The weight of evidence that an agent is a human carcinogen is determined by the quality and adequacy of the data for carcinogenicity as well as the nature and magnitude of the response. There is substantial justification for using rodent assay systems for predicting human responses because of the approximately 15 chemical agents that are generally accepted to have produced human cancers, all but one produced a carcinogenic response in rats and/or mice; in most of the tests, the cancers occur in the same organ as in humans when tested by the appropriate route of exposure. There are only a few instances where the conventional bioassay tests by ingestion or inhalation with rats and mice produced false negative results; i.e., tests with other species or routes of administration were required to produce positive results. It is to be expected that the rodent assay systems will also produce false positive results, but there is no evidence upon which to base judgments of how frequently and with what classes of agents this is likely to occur.

The quantitative assessment of the impact of a suspect carcinogen on cancer induction in humans at unregulated levels of exposure is necessary because otherwise there would be no basis for judging the need for regulatory action. Of the half a dozen cases in which quantitative comparisons can be made between animals and humans, the magnitude of carcinogenic response in the most sensitive of the tested animals does show a reasonable comparability to that of humans. Such comparisons also indicate that there can be enormous differences in the carcinogenic potency of different agents for both humans and animals. However, it is necessary to recognize that there are substantial differences in sensitivity even amongst different strains in the same species of test animals so that it is necessary to take cross comparisons between animals and humans with reservations.

Another aspect of the quantitative risk assessment involves extrapolation of dose-response relationships from high levels of exposure to low levels of exposure. All the instances that we have of human cancer induction by known chemical and physical agents as well as the induction of cancers in animals involve large exposures in comparison to those which are of concern in setting exposure standards. Estimates are, therefore, required about the level of cancer risk at exposures which are far below those for which observable responses have been obtained. In order to make such extrapolations, it is necessary to assume some shape to the dose-response curve. For this purpose, it is probably most appropriate to assume a linear non-threshold dose-response relationship. This pattern of response has been observed in humans with certain forms of ionizing radiation and with the occurrence of lung cancer by cigarette smoking. It is also the pattern of response observed for the induction of genetic mutations and there is a strong possibility that genetic damage is the fundamental derangement in cancer cells. The linear non-threshold dose-response relationship is conservative in tending to predict the largest response for any given level of low dose exposure. Such a dose-response pattern, however, carries the implication that there is no such thing as a safe level of exposure.

SUMMARY

The intent of the EPA Interim Guideline for Carcinogen Risk Assessment is to provide a summation of the evidence about a suspect carcinogen which encapsulates judgments about the quality and adequacy of data, the likelihood that the agent is a human carcinogen, and an estimate of the magnitude of the cancer burden that could be ascribed to the agent if no regulatory action were taken. It is recognized that new knowledge in the field of carcinogenesis is rapidly developing and that modifications of the Guidelines for Risk Assessment will need to be made periodically.

DRAFT INTERIM GUIDELINE FOR CARCINOGEN RISK ASSESSMENT

1.0 Introduction

This preliminary guideline describes the general framework to be followed in developing an analysis of carcinogen risks and some salient principles to be used in evaluating the quality of data and formulating judgments concerning the nature and magnitude of the cancer hazard from suspect carcinogens.

This guideline is to be used within the policy framework already provided by applicable statutes, and does not alter such policies. The guideline provides a general format for analyzing and organizing available data. It does not imply that one kind of data or another is prerequisite for regulatory action to control, prohibit, or allow the use of a carcinogen. Also, the guideline does not change any statutorily prescribed standards as to which party has the responsibility of demonstrating the safety, or alternatively the risk, of an agent.

The analysis of health risks will be carried out independently from considerations of the socio-economic consequences of regulatory action.

The risk assessment document will contain or identify by reference the background material essential to substantiate the evaluations contained therein.

2.0 General Principles Concerning the Assessment of Carcinogenesis Data

The central purpose of the health risk assessment is to provide a judgment concerning the weight of evidence that an agent is a potential human carcinogen and, if so, how great an impact it is likely to have on public health.

Judgments about the weight of evidence involve considerations of the quality and adequacy of the data, and the kinds of responses induced by the suspect carcinogen. The best evidence that an agent is a human carcinogen comes from epidemiological studies in conjunction with confirmatory animal tests. Substantial evidence is provided by animal tests that demonstrate the induction of malignant tumors in one or more species including benign tumors that are generally recognized as early stages of malignancies. Suggestive evidence includes the induction of only those non-life shortening benign tumors which are generally accepted as not progressing to malignancy, and indirect tests of tumorigenic activity, such as matagenicity, in-vitro cell transformation, and initiation-promotion skin tests in mice. Ancillary reasons that bear on judgments about carcinogenic potential, e.g., evidence from systematic studies that relate chemical structure to carcinogenicity should be included in the assessment.

When an agent is assumed to be a human carcinogen, estimates should be made of its possible impact on public health at current and anticipated levels of exposure. The available techniques for assessing the magnitude of cancer risk to human populations on the basis of animal data only are very crude due to uncertainties in the extrapolation of dose-response data to very low dose levels and also because of differences in levels of susceptibility of animals and humans. Hence, the risk estimates should be regarded only as rough indications of effect. Where appropriate, a range of estimates should be given on the basis of several modes of extrapolation.

Expert scientific judgments in the areas of toxicology, pathology, biometry, and epidemiology are required to resolve uncertainties about the quality, adequacy, and interpretation of experimental and epidemiology data to be used for the risk assessment.

3.0 Format of the Risk Analysis

3.1 EXPOSURE PATTERNS

This section should summarize the known and possible modes of exposure attendant to the various uses of the agent. It should include or identify by reference available data on factors relevant to effective dosage, physical and chemical parameters, e.g., solubility, particle size for aerosols, skin penetration, absorption rates, etc. Interaction of agents which may produce a synergistic or antagonistic effect should also be indicated, if available.

3.2 METABOLIC CHARACTERISTICS

This section should summarize known metabolic characteristics including transport, fate and excretion, and biochemical similarities to other known classes of carcinogens at high and low dose levels and should provide comparisons between relevant species as well as variations in different strains of certain species.

3.3 EXPERIMENTAL CARCINOGENESIS STUDIES

Available experimental reports should be summarized. If some experiments are to be rejected for the risk assessment, give reasons for doing so. Reprints of key papers and reports should be included as appendices to the analysis.

Judgments should be provided on the quality of the experimental data and their interpretations for each study on the basis of (1) experimental protocols, (2) survival rates in controls particularly in relation to acceptance of negative results, (3) incidence of spontaneous tumors in the control compared to general laboratory experience for the same species or strain, (4) diagnostic criteria and nomenclature used for tumor characterization (additional evaluation of histological material should be obtained when appropriate), (5) observed results of positive controls (i.e., a test group given a standardized exposure to a known carcinogen) in light of expected results.

3.4 EPIDEMIOLOGICAL STUDIES

Summarize epidemiological studies, together with critiques of the work with respect to its limitations and significance. Summarize other published critiques whether supportive or at variance with the judgment made here.

3.5 CANCER RISK ESTIMATES

3.5.1 *Exposure Patterns* — Describe likely exposure levels with respect to long-term temporal trends, short-term temporal patterns, and weighted averages for both the total exposed populations and for subgroups whose exposure patterns may be distinctly different from the average. Characterize, to the extent possible, the size of the exposed population for each of the above categories with an indication of whether the exposures are likely to involve children and pregnant women. Discuss the adequacy of the methods used to estimate exposures and indicate the range of uncertainty in the estimates.

3.5.2 *Dose-Response Relationships* — Both human and animal data should be used as available. Include available human data, even if inadequate for a characterization of the actual magnitude of risk, where such data could be helpful in interpreting animal responses in relation to human sensitivity.

3.5.3 *Estimates of Cancer Risk* — The procedure will involve a variety of risk extrapolation models, e.g., the linear non-threshold model and the log-probit model. Analyses will be done separately for all suitable experimental data and human epidemiological data. The results should be presented in terms of excess lifetime incidence, or average excess cancer rates; life-shortening estimates should also be made when the data permit. The uncertainty in the data and extropolation techniques should be clearly indicated. The results predicted for humans should be presented in relationship to the current cancer experience in the assumed target organ(s).

Some judgments should be included regarding the relevance of the mode of exposure used in animal studies to that associated with human exposure.

4.0 Summary

The summary section of the risk assessment should provide a statement which encompasses answers to the following questions: (1) How likely is the agent to be a human carcinogen? (2) If the agent is a human carcinogen, what is the estimated impact on human health?

GENETIC ASPECTS OF PERMISSIBLE LOAD DETERMINATION

L. M. FILIPPOVA

In determining the scientifically substantiated magnitude of the permissible influence of environmental factors in the individual or population aspect we are faced with the need to consider all the possible types of harmful effects of an entire complex of factors affecting an organism. With an increase in our knowledge and the accumulation of information in this area of research there becomes increasingly more important that part of the so-called "genotoxic" (a lethal, toxic and mutational complex) effect which is connected with the genetic consequences of environmental pollution. Mutationally active chemical compounds, which are encountered among industrial wastes emitted into the natural environment, among synthetic industrial products and food additives, which increase the frequency of genetic and chromosomal mutations in the gametes and somatic cells of man, are becoming the cause of an increase in the number of hereditary diseases and defects, congenital anomalies, stillbirths and spontaneous miscarriages. No small role is played by the increase in the intensity of the mutation process in animal and plant populations, which leads as a rule to a decrease in their vitality and a deterioration of the qualitative characteristics.

The influence of chemical factors having a mutagenic activity can lead to diverse genetic consequences for individual organisms, populations and ecosystems. At the level of ecosystems the increase caused by these factors in the intensity of the mutation process among populations belonging to this ecosystem may lead to a change in its structure, which will be expressed in the gradual disappearance of all the populations of the ecosystem sensitive to this influence and to the consolidation of all those resistant to it. The disturbance of the stability of the ecosystem, its degradation may become the result of such a restructuring. Most dangerous are similar influences and similar changes for long existing, stable, isolated ecosystems.

In the individual aspect the existence of mutagenes in the environment entails the threat of deterioration of the state of health, the shortening of the life expectancy, as well as the emergence of cancerous diseases through the induction of mutations in the somatic cells of people subject to the influence.

Most serious in the aspect being examined is the population level. Each population is characterized by its own evolutionarily established correlation of the mutation process that saturates the population with harmful mutations, and the process which eliminates defective genes from the population. An increase in the intensity of the mutation process, if it is not great, will not have any serious consequences in the case of open populations with a large number of individuals. What has been said, however, does not apply to human populations. Characteristic of the human population at present is a constant decrease in the pressure of selection; in connection with this it becomes evident what the significance is of the observed increase in the pressure of mutations against a background of the already considerable existing genetic threat in the population. Table 1 shows the change in the number of affected individuals in the population with a doubling of the frequency of mutations from 10^{-6} to 2×10^{-6} for four types of genes [1].

TABLE 1.

Type of Defective Gene	Number of Affected Individuals per Million		
	Initial Equilibrium	After One Generation	New Equilibrium
Recessive*	1 aa	1.002 aa	2 aa
Semidominant	20 Aa	20 Aa	40 Aa
Dominant*	2 Aa	4 Aa	4 Aa
Linked with Sex*	3 aY	4 aY	6 aY

* In the first, third and fourth instances the affected individuals are incapable of reproduction.

The same changes may occur when the frequency of mutations is unchanged but the pressure of selection is reduced by 50%.

It was only comparatively recently, yet now everyone recognizes the need to evaluate the permissible levels of influence of mutagenic agents in addition to the traditional setting of toxicological standards of pollutants in man's environment. Considering the fact that the combination of pollutants being admitted into the natural environment is becoming increasingly diverse, while the amount of each of them is constantly growing, very important is the need to evaluate the relative contribution of the most diverse environmental factors having a mutagenic activity. Keeping in mind the experimentally demonstrated potential of an adaptive or synergidal mutation effect, when determining the permissible amounts of genetically active pollutants in natural environments it is necessary to consider not only the interaction of these substances, but also the increase in the frequency of mutations, which is caused by the influence of products of chemical synthesis and other factors in production, industry and agriculture, as well as in daily life. Each of these spheres of human life is characterized by a specific set of genetically active agents that comes into contact with man. As an example we can cite the results of our research on the mutagenic danger of certain groups of medicinal compounds. The bulk of strong chemical mutagenes is found among medicinal compounds used in cancer chemotherapy, but other classes of pharmacological preparations also contain a significant amount of mutagenically active compounds. We studied a group of psychotropic drugs now being used extensively throughout the world and often without regulation, and, what is very important, primarily by people of childbearing age [2, 3]. Of 47 compounds 12 substantially increased the frequency of the appearance of gene mutations and or chromosomal aberrations; among the mutagenically active compounds was such a very widespread drug as Luminal (phenobarbital). The existence of such a large number of mutagenically active compounds in the studied selection of psychotropic drugs, which are in no way deliberately mutagenic, as in the case of cancerolytic drugs, attests to the significant contribution to the overall mutational load on the human population by pharmacological preparations.

In environmental toxicology there are two approaches to the setting of standards for the content of harmful substances, i.e., to the determination of the permissible loads on the human body. The first approach is traditional, it has been at the basis of the development of environmental hygiene in recent decades. This approach has as its theoretical foundation the concept of the threshold nature of the influence of toxic substances and consists in determining their threshold amounts. The maximum permissible concentration of a substance (MPC) in natural environments is a threshold, and according to this concept, an absolutely safe amount of this substance, and therefore, there is no possibility of any influence from the toxic substance on the human organism. The concept of a threshold nature of the effect of harmful substances leads to the very serious and, in our opinion, doubtful conclusion that no matter how numerous the environmental polluting compounds and factors, their simultaneous presence is absolutely harmless if the amount of each of them does not exceed the MPC.

Recently among toxicologists developing norms and standards of the content of substances polluting the natural environment, recognition has been gained by the conception according to which any, even the smallest quantities of a harmful substance may have an influence on an organism, while the apparent threshold of the effect with the increase in our knowledge and the appearance of more perfect research techniques will gradually be lowered. In this case there can be no absolutely safe and guaranteed subthreshold quantities of toxic substances, and basic in determining the permissible amounts of harmful substances in natural environments is the question, what portion of the population will be subject to the harmful effects of a particular dose of the pollutant and to what extent. In this case the determination of the degree of permissible influence and permissible quantities of toxic substances in natural environments is no longer that clear and simple.

As we already stated in our report presented at the first symposium on the comprehensive analysis of the environment, when determining the permissible amounts of chemical compounds in the environment it is extremely important to proceed from the principle of the lack of a threshold of their mutational effect [4]. Hence ensues the very important conclusion that any amount of an active chemical mutagen can become the cause of serious genetic consequences for the human population. At present our knowledge of the laws of those processes in the human population which can lead to particular disturbances of the balance "mutations — selection" is limited, and approaches to the quantitative evaluation of the gentic risk of the factors of man's environment are only being developed; for this reason many geneticists assume that today it would be correct only to assert that any kind of influence on hereditary material and any amount of mutagenic substances (except for those found in natural conditions) in the natural environment are impermissible. Such an assertion, however, cannot satisfy us for the reason that the complete elimination of mutagenically active agents not only from the natural environment, but also from the daily sphere is impossible. Moreover, the benefit from using some product, even a mutagenically active one, can be just as great, but its replacement by another, nonmutagenic product for similar use is impossible. In this case we are forced to deliberately agree to some enhancement of the intensity of the mutation process in the population, and then the most important question would be, precisely what change in the intensity of the mutation process can be considered permissible.

The question, what influence of a mutagenic agent and what increase in the intensity of the mutation process in a human population under the influence of environmental factors can be considered permissible, for the most part has been worked out for ionizing radiation [5]. A BEIR report, published in 1972, postulated that if the genetically significant dose of ionizing radiation is lower than the natural background of radiation taken as a standard of comparison, then the genetic consequences caused by this influence will not differ quantitatively or qualitatively from those experienced by mankind in the history of its development. Taken as the criterion of permissibility of an influence was a double dose, i.e., the dose of radiation necessary to induce the same number of mutations observed under natural conditions; its magnitude was calculated on an interval of from 20 to 200 rem. Adopted as the standard of permissible influence for the basic population was a dose of 170 mrem annually from all nonmedical artificial sources of radiation.

The vast diversity of chemical agents in man's environment, the pronounced specificity and differences in the mechanisms of their effect make the task of determining the permissible genetic stress much more complicated than in the case of radiation agents. Approaches to evaluating the permissible amounts of chemical mutagenes, the permissible levels of influence on the intensity of the mutation process in the human population are only beginning to be developed.

Of course, it would be illogical to examine the genetic risk of chemical mutagenes and radiation in isolation of each other and not to use the positive experience of development of this question for radiation agents; therefore when evaluating the permissible influence of chemical mutagenes in the environment it was proposed to use the principles elaborated for radiation mutagenes [6,7]. A number of authors proposed to express the degree of mutagenic risk of factors by comparison with a radiation-equivalent dose; even earlier we used this approach in a work devoted to the study of the genetic hazard of drugs [8].

Special units were proposed for such an evaluation of the effect of chemical mutagenes: RED roentgen equivalent dose [6], radeq (radequivalent) [7,9], REC (rem-equivalent-chemical) [10]. Thus, the determination of the genetic risk of chemical mutagenes under normal environmental conditions should be made by extrapolation of the experimental data according to the dependency "dose-effect" (in the opinion of most, it should be assumed as linear) and the subsequent risk in terms of the dose of radiation causing the same effect. Thus [9], if *in vitro* there is the probability of the appearance of m gene mutations with an exposure time to t hours of mutagenesis at a concentration c, then the concentration c x 10^{-3} under the conditions *in vivo* can cause a genetic effect of

$$\frac{m}{c} \times \frac{c}{1000} \times \frac{1}{t}$$

or m/1000t per hour of exposure.

If the same effect can occur under the influence of b rad of radioactive irradiation, then m/1000t is the equivalent of b rad or equal to b "radequiv." The magnitude thus obtained can be compared with the already established standard of the maximum permissible dose (about 0.17 rad/year) in excess of the spontaneous level of radiation.

A recent survey [10] prepared by a group of specialists (Committee 17) contains some recommendations on evaluating the genetic risk of chemical mutagenes and determining the permissible levels of influence of mutagenes on man. It is proposed that the permissible level of total mutagenic influence of synthetic chemical compounds, as well as of radiation, be equivalent to 5 rem/generation, in conformity with the BEIR commission, excluding radiation and chemical compounds used for medical purposes. With a double dose of 40 rem this corresponds to an increase in the intensity of the spontaneous mutation process by 12.5% [(5/40) x 100]. The effect of any single mutagenic agent should not exceed 10% of the total norm of 5 REC, which is the maximum permissible for an entire complex of mutagenic agents. It is proposed to take this level as the absolute level, although the limitation to 10% has no scientific basis, but was established by proceeding from the consideration that the appearance in the same place and at the same time of 10 active mutagenes is unlikely.

The work of N. P. Bochkov et al. [11] suggested proceeding from the indicator of the intensity of the spontaneous mutation process when evaluating the genetic risk of chemical mutagenes; placed at the basis of the evaluation of the mutagenic danger of some chemical mutagene was the extent of the increase in the spontaneous level of mutations of the test object, converted to the average dose and exposure time of the given substance in the human population. The authors proposed that in the population aspect the maximum permissible dose be the average population dose that causes an increase in the spontaneous level of not more than 0.1%; in the individual aspect a doubling of the level of the spontaneous mutation process should be taken as the maximum permissible influence.

No one can doubt that no compound, even one which is of great benefit, can be allowed to be used if its mutagenicity exceeds the permissible level; it is also evident that it is impermissible to use a mutagenically active compound that is not of great value for man. If the mutagenic activity of a valuable product of chemical synthesis is lower than the maximum permissible level, the cost-benefit analysis, the results of which should determine the volume and form of use of this product by man, becomes the main task.

The question of the economic evaluation of the damage of environmental pollution has been worked out only in its general outlines. Earlier [5], an attempt was made to evaluate in dollars the cost (economic damage) of the influence of radiation on man. The total cost of a dose of 1 rem per person in concepts of the cost to health was between 12 and 120 dollars. The opinion was expressed [10] that the sample principles of evaluation can be applied to determination of the damage from chemical mutagenes, if their activity is expressed in the units GSC (genetically significant concentration) and REC.

CONCLUSION

At present the need has become evident not only for a study of the mutagenic activity of environmental factors, but also for an evaluation of the permissible amounts of mutagenic agents and the permissible levels of the influence on the individual organism and populations. In elaborating the problem of protecting the human genetic stock from the harmful influence of environmental factors we should name the following as the most important tasks whose resolution will be the basis of regulation of the content of genetically active compounds in the environment:

—Development of adequate models and test objects, which are the most informative and minimize the problem of extrapolating the data to man, for determining the genetic activity of chemical agents in the environment, as well as the principles of selection and the sequence (priority) of their testing.

—Determination of a scientifically sound magnitude of the permissible influence of an entire complex of mutagenic compounds and separate chemical mutagenes on the human population.

—Development of methods for evaluating the genetic damage and the expenditure which society is forced to bear as a result of the use and the presence in the environment of a mutagenic compound.

In spite of the fact that modern approaches to determining permissible levels of influence of chemical mutagenes on the human population are in many respects imperfect, qualitative and intuitive, it is fundamentally important already today to develop methods for regulating the content of chemical agents in the natural environment, as well as in the production and everyday spheres. Right now it is necessary to shift to practical measures on limiting the number and volume of chemical mutagenes coming into contact with man; the extent of limitation should be determined by conducting a cost-benefit analysis for chemical products which have for society a pronounced benefit and do not exceed the permissible (according to present notions) levels of influence on the intensity of the mutation process in the human population.

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BIOLOGICAL EFFECTS OF NON-IONIZING RADIATION

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INTRODUCTION

Reports from American laboratories describe biological effects from exposure to non-ionizing radiations such as the high frequency microwaves and radio waves and low frequencies near that of U.S. electrical power (60 Hz). The non-ionizing electromagnetic radiation spectrum includes the radio, microwave, infrared, visible and most of the ultraviolet frequencies. The microwave region refers to the upper part of the radio frequency spectrum from 300 MHz to 300 GHz with corresponding wavelengths from 100 to 0.1 cm.

The energy of a 2450 MHz photon is approximately 1×10^{-5} electron volts which is more than one million times too low to produce the ionizations caused by the higher frequency x-rays and gamma-rays. Hence, the name non-ionizing electromagnetic radiation. For comparison, a visible light photon is about 100,000 times more energetic than a photon at microwave frequencies.

A mechanism by which microwave radiation can deposit energy in a biological system is by heating [1-3]. This process may be partially explained by 2 electrophysical properties of water. The water molecule is an electrical dipole which tends to align itself along the lines of force in an electric field. The other pertinent property of water is its lengthy relaxation time which prevents the net dipole moment for water from quickly and completely aligning in a rapidly oscillating electric field. Microwave heating of biological samples is due to the molecular friction caused by water and other dipoles, such as proteins, being unable to complete their rotational motion in time with each oscillation of the rapidly changing electric field. When ions are present, ionic conduction also contributes significantly to heating. The energy of the incident electromagnetic waves is transformed into increased kinetic energy of the absorbing molecules and thus to an increase in temperature. This is the process that cooks food in a microwave oven and is the principle of the therapeutic use of microwave radiation in diathermy units in hospitals for heating of tissues deep within the body.

The heating effect of microwave and radio frequency radiation is the basis for the U.S. protection guide for occupational exposure. The American National Standards Institute (ANSI) guide of 10 mW/cm^2 for radio frequency exposures, which was recommended in 1966 and reaffirmed in 1973, is roughly a factor of ten below thresholds of biological damage by thermal effects [4,5]. This exposure level also takes into account the amount of exogenous heat which the human body can tolerate and dissipate without a rise in body temperature. The guide of 10 mW/cm^2 applies to pulsed and continuous wave radiation in the frequency range from 10 MHz to 100 GHz.

Establishment of an exposure guide has not quieted the concern for possible health hazards for two reasons. First, since World War II, equipment utilizing the radio and microwave frequencies has proliferated to the extent that the potential exists for humans to be exposed to appreciable levels of these man-made forms of radiation. Examples of this equipment include radio and television broadcast transmitters, radar, diathermy and blood-warming units, cooking and drying ovens, communication devices, and industrial machines.

Second, the U.S. guide is up to 1000 times greater than standards established in the USSR and Eastern Europe [6]. In contrast to our exposure guide which is based on thermal effects, the Soviet standard is based on their research on central nervous system and behavioral effects of non-ionizing radiation [2]. Our present research is directed towards determining the reasons for the discrepancy in exposure guides and determining whether our safety limit applies across a wide frequency band and to different types of modulation. We are asking ourselves the questions: Are there subtle biological interactions of non-ionizing radiation which cannot be reproduced by conventional (non-microwave) thermal means? Are there direct interactions between microwave radiation and tissues, such as transduction by biological membranes, which can cause physiological effects? If so, what are the physical mechanisms by which these interactions occur?

Some experiments that bear on these questions are described below.

CATARACTS

The heat exchange capacity of the circulatory system is one of the protective mechanisms for dissipation of excessive thermal energy; therefore, a tissue's susceptibility to thermal damage by microwave radiation is related to its vascularity. A tissue which is completely a-vascular is the lens of the eye. Cataracts are produced in the lenses of experimental animals given short (single or multiple) exposures to microwaves at high power densities. For laboratory animals, investigations suggest a threshold of cataract formation from acute exposures in excess of 100 mW/cm² [7]. Thermal effects such as this led to the development of the U.S. exposure guide.

At present, a threshold value for human cataractogenesis cannot be determined, although it would appear to be in excess of 100 mW/cm² because microwave diathermy has been used for many years pre- and post-operatively on the eye. The usual treatment of about 100 mW/cm² for 20 minutes is often given twice a day for up to 2 weeks. No adverse effects of this treatment have been seen [8]. Beyond the question of the threshold value for man, there is a controversy over the effects of different exposure conditions such as the cumulative effects of chronic exposure, nonthermal effects, and pulsed versus continuous wave effects [9,10].

GENETIC EFFECTS

It is well known that the testes possess a vascular system inadequate for rapid heat transfer and that sperm are very sensitive to heat. Almost all studies on the effects of microwaves on testicular tissue describe results primarily of thermal origin due to high power density irradiation [6].

Genetic damage is a biological hazard which must be considered for every chemical and physical agent to which humans are exposed. The genetic code is contained in DNA (deoxyribonucleic acid) which is the basic information molecule in chromosomes. The significance of chromosomal aberrations is that any induced mutations may have somatic consequences to the recipient and genetic consequences to the offspring. Chromosomal aberrations have been observed in both human and animal cells in culture after irradiation (2450 MHz) at power density levels below the U.S. exposure guide [11,12]. Such *in vitro* results have to be considered with a great deal of concern. This is especially true if the effects can be produced by irradiating the whole animal. However, a 1974 review article states that "no *in vivo* investigations of the effect of radio-frequency or microwaves on mammalian chromosomes have been conducted at power levels sufficiently low to avoid heating the animal" [6].

A current study sponsored by EPA will provide information on the cytogenetic effect of microwave exposure of animals. In our facilities in the Experimental Biology Division, Chinese hamsters* are irradiated at 2450 MHz at power densities of 5 to 30 mW/cm². Blood cells from the animals are subsequently analyzed for chromosomal abberations at the Duke University Medical Center. Preliminary data indicate that these levels of radiation do not produce abnormal chromosomes in hamster lymphocytes. The differing *in vivo* and *in vitro* results have yet to be reconciled.

BEHAVIOR

A simple behavioral experiment has demonstrated that rats can "detect" pulsed microwave radiation (1.2 GHz) at an average power density of 0.2 mW/cm² [13]. The experimental animals were placed in a box divided in half by a low fence. One half of the box was exposed to microwaves; the other half was shielded from radiation. Animals tended to avoid pulsed radio waves by spending significantly more time in the shielded half of the shuttle box. This effect was not seen with continuous wave radiation.

In a subsequent experiment an association was found between this change in behavior and in brain permeability [13]. Animals were exposed to microwave energy under the same conditions that yielded the behavioral modification and, immediately after irradiation, a dye was injected into the bloodstream. The dye, sodium fluorescein, binds to serum proteins and is used to study the permeability of the brain to these large molecules. An increase in fluorescence was seen in the brain of exposed rats compared to that of controls which indicated a breakdown in the blood-brain barrier. Interestingly, both pulsed and continuous wave radiations caused a change in the brain barrier, however, pulsed radio waves produced a greater effect. Only pulsed radiation caused a change in behavior in the shuttle box. The authors concluded: "It appears that RF electromagnetic energy affects brain permeability and behavior and that pulsed energy is more effective than CW energy in affecting said brain permeability and behavior. These results indicate that there is an association between behavioral modification and brain permeability changes when similar RF energy parameters are employed" [13].

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*Chinese hamsters are the animal of choice for cytogenetic studies because each cell contains only 22 chromosomes compared to man's 46.

Scientists at the Naval Medical Research Institute have studied the effects of low levels (1 to 20 mW/cm^2) of pulsed (2860 and 9600 MHz) and continuous wave (2450 MHz) microwave radiation on conditioned behavioral patterns [14]. For example, rats trained to respond (press a lever) a specific number of times to produce a food pellet had a lower rate of response after microwave irradiation. Subtle changes in performance patterns in this and other behavioral tasks were reported at exposures as low as 5 mW/cm^2. These effects are interpreted as interactions of microwave radiation at low power levels with the central nervous system as opposed to possible thermal stress caused by higher power densities.

Experiments conducted at the UCLA Brain Research Institute have shown behavioral, electroencephalographic (EEG) and biophysical/chemical effects of very low frequency (ELF region) and modulated very high frequency (VHF) radiations. For example, monkeys trained to subjectively estimate a five second time interval without external cues showed a significant shortening of their estimation of the time interval when exposed to a 7 Hz electric field at 10 V/m* [15-17]. In addition, EEG recordings showed the gradual appearance of enhanced rhythms at the 7 Hz field frequency. Similar behavioral and EEG effects were observed at 45 and 75 Hz but higher electric fields were required. Effects at fields of 100 V/m were so permeating that the animal's performance was affected 24 hours later.

The EEG patterns showed two principal trends. During irradiation, a sharp decrease was seen in the very low brain frequencies (e.g., 1 and 2 Hz), and, although not very pronounced, any naturally occurring brain wave which matched a radiation frequency seemed to be enhanced (e.g., 7 Hz) [17]. Similar effects on EEG recordings were observed in animals exposed to a weak electromagnetic field (1 mW/cm^2) at a very high frequency (VHF, 147 MHz) amplitude modulated at brain wave frequencies. That is, EEG signals recorded in specific brain areas were enhanced in their frequency of occurrence by the presence of the VHF field modulated at the same frequency [19].

The UCLA scientists have sought the basis of these apparently direct interactions of extremely low (ELF) and radio frequency fields with the brain in a series of biochemical studies. They hypothesized that the electrical forces induced in brain tissue by the fields could trigger local conformational changes in the macromolecular structure of the outer zone of the neuronal membrane [20]. These changes would result in displacement of cations bound to the macromolecular glycoproteins of the outer surface of the classical lipid bilayer membrane. The glycoproteins are loosely arranged, highly hydrated, and have numerous fixed negative charges. Because of its affinity for cations, particularly calcium and hydrogen, this outer zone may function as an electrochemical energy transducer. To study one step in this process, experiments were conducted to measure movement of calcium ions in brain tissue *in vitro* following irradiation with the VHF field amplitude modulated at EEG frequencies. Thus, the exposure conditions in this experiment were like those employed in the experiments which showed EEG effects. Exposures to fields modulated at 9, 11, 16 and 20 Hz caused a 10 to 20% increase in calcium efflux [21]. The significance of this change is related to the finding that calcium binding and release has been linked to inhibition and excitation in the cerebral cortex.

HEART

An effect of microwave radiation on the heart may be due to an interaction with the nervous system of this organ. University of Utah scientists have shown that microwaves (960 MHz, continuous wave) change the rate at which the isolated turtle heart beats in an unexpected way [22]. A decrease in heart rate (bradycardia) occurred upon irradiation in a certain low power range. Since the turtle is cold blooded (poikilothermic), the heart beat will increase with an increase in temperature; therefore, the decrease in beat rate cannot be explained by generalized heating of absorbed microwave energy.

The scientists hypothesized that the radiation is stimulating remnants of the involuntary (autonomic) nervous system. In general, if the parasympathetic nerves are stimulated, the heart rate decreases. If the sympathetic nerves are stimulated, the rate increases. Addition of atropine, which will block the action of the parasympathetic nerves, will cause a transient increase in the heart beat. If the atropine-treated heart is irradiated after the beat rate has returned to the control level, an increase in beat frequency occurs instead of the decrease observed in the untreated sample. These results suggest an interaction of low level microwave radiation with the nervous system of the heart. The effect has been repeated with isolated mammalian (rat) hearts [23]. Pronounced bradycardia was observed within two minutes after irradiation of 1.5 to 2.5 mW/cm^2. Furthermore, the heart rate showed both a regular decrease and temporarily stopped for 5 to 12 seconds.

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*Smith and Brown [18] reported that ambient levels originating primarily from AM broadcast transmitters and radar installations in the Washington, D.C. area approached 0.01 mW/cm^2 (6 V/m).

GROWTH AND DEVELOPMENT

Although mammalian experiments have generally failed to show growth and development defects due to microwave radiation at low power, exposures of the darkling beetle (*Tenebrio molitor*) to 9 GHz radiation has caused teratological damage at dosages as low as 0.4mWhr (0.2 mW applied for 2 hours). The authors suggest the possibility that microwave radiation is a cumulative teratogen in the beetle [24]. This report reproduced earlier research [25,26] describing such damage and extended the threshold value for teratogenesis to a lower value. Still to be answered is the question of how the microwaves interacted with the insect larvae and produced the effect (discrete holes in the elytra). Transient or localized thermal effects have not been eliminated as a mechanism of interaction in these experiments.

RF HEARING

Some humans can "hear" microwaves, a phenomenon called RF (radio frequency) hearing [27-29]. The sensations are similar to clicks, buzzes, pops and hisses which are localized slightly behind the head on the sagital midline. The RF induced response is an auditory sensation which is distinct from and not dependent upon normal air conduction hearing. To hear microwave energy, it must be pulsed. The sensation is dependent on peak power of the pulse and has an average power threshold of about 0.4 mW/cm². Perception occurs upon irradiation of pulsed ultra high frequencies (UHF) at 300-3000 MHz.

Recent research has suggested that the sensation is due to a transient thermal expansion phenomenon. [30]. A microphone suspended in a container of water irradiated by pulsed microwaves delivered an audio output similar to that "heard" by directly radiated human subjects. Since water changes density as its temperature is altered, the miniscule thermalizations produced in it upon absorption of the pulsed microwaves were sufficient to initiate small but detectable changes of hydraulic pressure. Other investigators have demonstrated sonic transduction of pulsed microwaves in materials lacking water [31]. The importance of these studies is related to an elucidation of one way non-ionizing electromagnetic radiation at low power levels that interacts with a biological system.

Some question the physiological significance of RF hearing. Others wonder at the possibility of psychological effects in people subjected to pulsed RF energy (which elicits the hearing sensations) who have no understanding of where or how the buzzes, clicks and hisses originate in their heads. On the other hand, the RF hearing phenomenon may lead to a means of communication with the deaf.

EXPERIMENTAL STUDIES

The Chinese hamsters used in the cytogenetic study mentioned earlier were irradiated in an exposure facility which operates at 2450 MHz, see Figure 1. Within the large chamber is a smaller one in which the animals were irradiated under controlled temperature and humidity conditions. The animal exposure box is constructed of polystyrene because this material is essentially transparent to the radiation and it also provides good temperature control. The inside walls of the chamber are lined with material that absorbs microwave energy and prevents reflections. Such a facility is called an anechoic chamber (no reflections or echoes). A similar radiation facility operates at 9 GHz and is used to study the effects of a pulsed microwave source, such as radar, on biological samples.

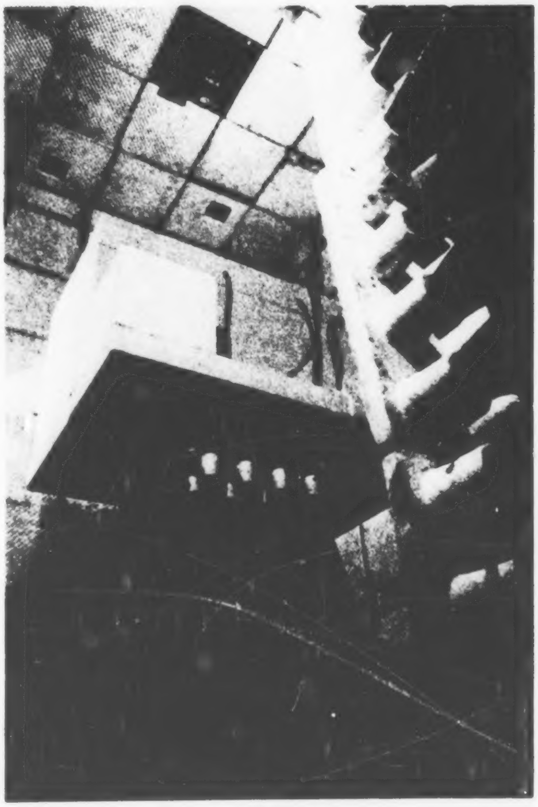

Figure 1. The 2450 MHz far-field exposure facility. The horn antenna (top) and the environmental exposure chamber (center) are visible in the shielded anechoic room. (Used by permission of Dr. Carl F. Blackman and the New York Academy of Sciences.)

In addition to the cytogenetic work, a variety of other experiments have been done, or are currently in progress, with these exposure chambers. These include growth and mutation studies with bacteria [32,33], yeast and fungi, respiration studies with mitochondria [34], immunological studies with animals and blood lymphocytes in culture [35], neurophysiological and behavioral effects in rats, and growth and developmental experiments with mice and rats.

A different type of irradiation system employs a coaxial air line, see Figure 2. This apparatus has been used to study the effects of microwave radiation in the frequency range from 2000 to 4000 MHz on respiration and oxidative phosphorylation in mitochondria [36]. The advantages of this system over the anechoic chamber are irradiation over a wide frequency range and easier and more accurate measurement of the power absorbed by the sample.

A final example of the EPA microwave exposure systems, called a crossed-beam exposure/detection apparatus, see Figure 3, combines microwave exposure of a sample with simultaneous spectrophotometric observation. This system offers a means of detecting transient effects of microwave radiation, i.e., those effects which may occur during the actual irradiation but do not persist upon termination of the exposure. Some of the experiments with irradiated protein and enzymes have been pertinent to establishing a mechanism of molecular interaction [37,38] as well as the use of 2450 MHz radiation to rapidly warm blood to body temperature before transfusion [39].

In one of the above studies, irradiation of animals with a frequency of 2450 MHz at power densities $\overline{<}$ 30 mW/cm^2 appears to stimulate the blood cells called lymphocytes to undergo cellular transformation to lymphoblasts. Experiments are underway to determine the threshold level of radiation which causes the effect in these cells which are involved in immunological reactions.

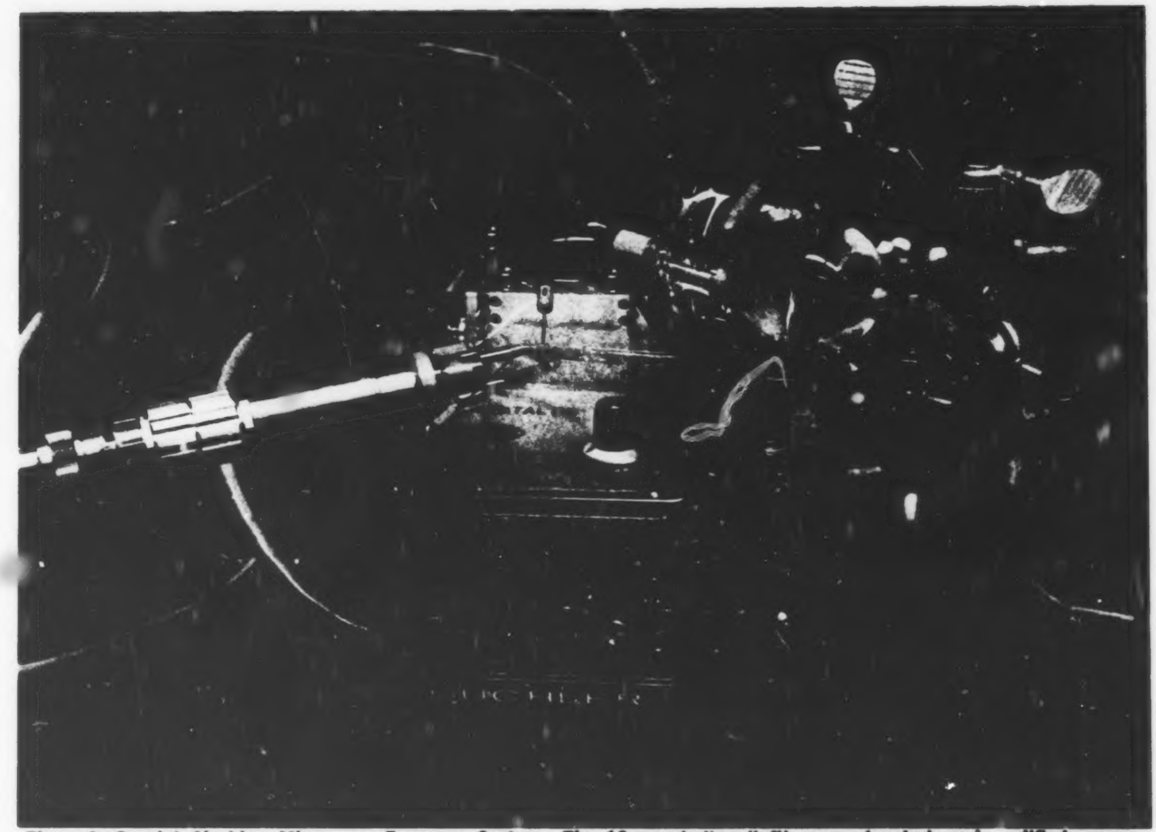

Figure 2. Coaxial Air Line Microwave Exposure System. The 10-cm air line (left), pump (center), and modified oxygen electrode cell (right) are shown. Hypodermic thermistors are inserted into the sample to measure temperature. The microwave generator is not shown.

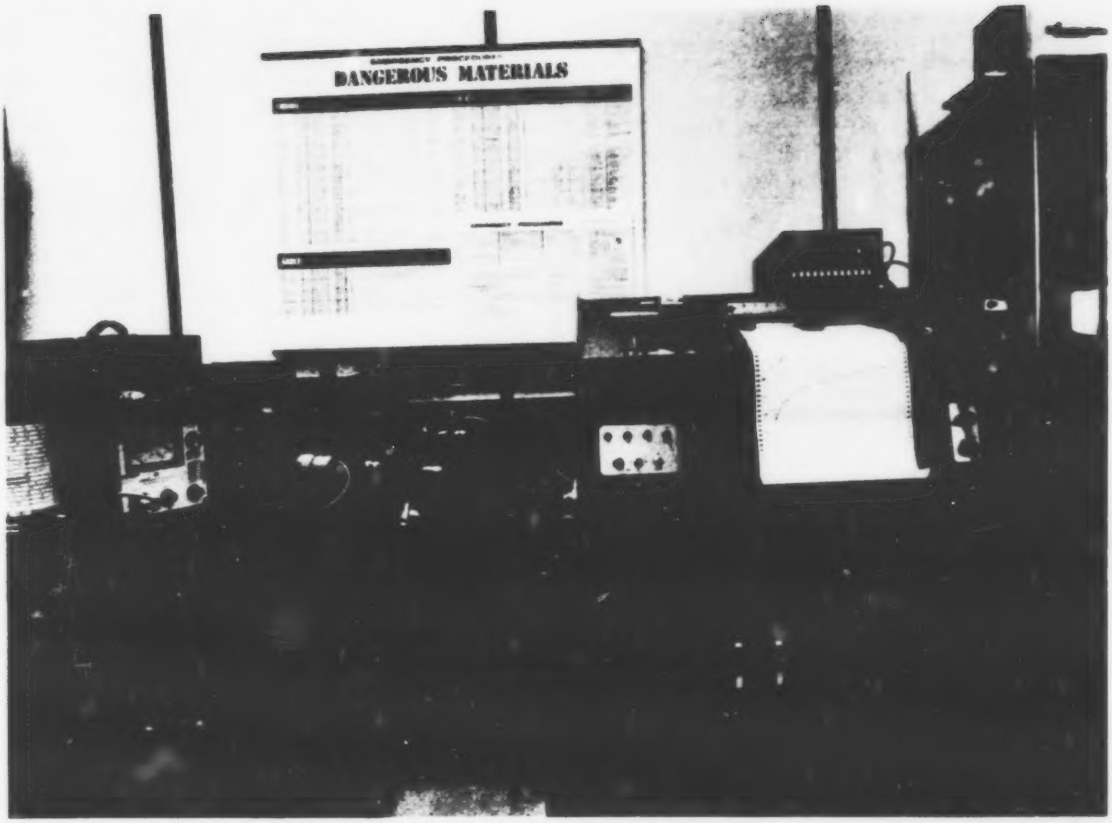

Figure 3. Crossed-beam exposure-detection system. The Cary 15 spectrophotometer is shown with a wave guide tuner and applicator suspended in the spectrophotometer sample compartment. At left is the AIL 125 microwave generator and two power meters to monitor forward and reflected power. On top of the Cary is a digital thermocouple thermometer that measures the temperature of the sample in the cuvette. (Used by permission of Dr. John W. Allis and the New York Academy of Sciences.)

SUMMARY

The U.S. exposure guide for occupational exposure to non-ionizing radiation which is based on thermal effects is up to 1000 times greater than standards established in the USSR. In contrast to the basis for our guide, Soviet standards as low as $10\ \mu W/cm^2$ are based on their research on central nervous system and behavioral effects. Exposures at this level will not produce thermal effects according to our present understanding of the interactions of non-ionizing radiation with biological systems. Our present research program is directed towards resolving the discrepancy in the safety limits and determining whether our exposure guide applies across a wide frequency range and to different types of modulation (e.g., pulsed versus continuous wave).

Reports from American laboratories have been reviewed which describe biological effects on the central nervous system (behavior, neurophysiology and neurochemistry), heart, chromosomes, and development, in addition to the RF hearing phenomenon, from exposure to low levels ($\lesssim 10\ mW/cm^2$) of non-ionizing electromagnetic radiation. The results at these low power levels suggest that they are apparently separate from generalized heating injury. However, some of the observations may eventually prove to be due to thermal effects because non-uniform distribution of the electromagnetic energy can cause the temperature in localized areas to exceed critical values. At the present time, these reports offer evidence for direct interactions of radio frequency and extremely low frequency electromagnetic waves with biological systems. Future studies will attempt to define the mechanisms of interactions by which low power levels of non-ionizing radiations cause biological effects. Concurrently, it is important to study the possible consequences of long-term, low-level environmental exposure. The research in this field will attempt to identify those biological effects of non-ionizing radiation which may be hazardous to human health and form a data base upon which to critically judge the U.S. exposure guide.

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POLLUTANTS AND PROGENY

K. DIANE COURTNEY

A very important aspect of the *Comprehensive Analysis of the Environment* is the consideration of the effects of pollutants on progeny. A pollutant is defined as any chemical or physical agent which adversely alters the development of an organism and therefore must be considered to be present in the organism's environment in excessive amounts. This immediately generates these questions: 1. What are the agents? 2. What alterations in development are being considered? 3. What are the amounts that are considered excessive?

There have been a number of examples of maldevelopment in human beings as a result of excessive exposures to these agents during critical stages of development. There have been epidemics of anatomical malformations, toxicological problems such as porphyria, and functional deviations such as cerebral palsy-type syndromes. The progeny constitute a unique sub-group of the human population. They are in a dynamic state of development and the response to an environmental agent is dependent on the stage of development as well as the dose and toxicologic properties of the agent. The following examples suggest the range of the problems encountered.

A number of years ago, Hertig studied very early human embryos from the time of fertilization up to 14 days of development [1]. He found that 40% of these embryos were abnormal and estimated that it would have been impossible for them to survive. Of course, there are a number of reasons that might explain what went wrong during these first few days of development. But when the question was asked — could toxic agents be the cause? — there were very few answers, because very few studies have been undertaken during this period of development. However, the study by Sieber should be considered [2].

C-14-DDT or H-3-nicotine were administered orally to rabbits that were six days pregnant and to non-pregnant rabbits also. One hour after the nicotine administration and 24 hours after DDT administration samples of maternal plasma, some of the uterine secretions, the endometrium and the developing blastocysts were taken for analyses. These results are presented in Table 1. The plasma levels of C-14-DDT in the pregnant and non-pregnant rabbits did not differ greatly. The endometrium of the non-pregnant rabbit had slightly more DDT than that of the pregnant rabbit. The significant finding was the high content of C-14-DDT in the uterine secretions of the pregnant rabbit since none was found in the non-pregnant rabbit. Of note was the C-14-DDT that was detected in the blastocysts. The findings with H-3-nicotine were quite similar. There was a high content of H-3-nicotine in the uterine secretions of the pregnant rabbit compared to the non-pregnant rabbit. The blastocysts contained a measureable amount. Even though the blastocysts had not yet implanted and thus did not have the placenta to supply nutrients or transport toxic agents, the blastocysts accumulated both C-14-DDT and H-3-nicotine. It is quite conceivable that some of the very early reproductive failures could be due to toxic agents affecting the blastocyst at this early stage of development. The data to evaluate the effects of pollutants at this stage of development are not available; many studies need to be done.

TABLE 1. ADMINISTRATION OF C-14-DDT OR H-3-NICOTINE TO 6 DAY PREGNANT RABBITS, PERCENT OF ADMINISTERED DOSE*

	C-14-DDT		H-3-Nicotine	
Item	Nonpregnant	Pregnant	Nonpregnant	Pregnant
Plasma	0.91	0.84	1.18	1.15
Endometrium	0.88	0.47	0.79	1.49
Uterine secretions	none	3.60	1.84	10.71
Blastocysts	–	0.13	–	2.26

*From Sieber, S. M., and Fabro, S., JPET 176, 65-75, 1971.

The next major phase of development to consider is the embryonic period. It is during this phase that the placenta forms and organogenesis occurs. And this time, insults to the embryo from pollutants could result in anatomical malformations. They can be called anatomical malformations, congenital malformations, birth defects or teratogenic effects. The most publicized example of a teratogenic agent was thalidomide. In the early 1960's, thalidomide caused birth defects mainly of the arms and legs in many children. Thalidomide was a therapeutic agent and would not be considered an environmental pollutant; however, it is an example of a major teratogenic agent affecting quite a large population. It took a number of years before thalidomide was documented as the causative agent. If the malformations had been more subtle and less obvious, one questions how long it would have taken to detect the increase in the incidence of malformed infants and to establish the cause.

Kelsey [1] reported that to detect an increase in the incidence of a malformation from 1 per 1,000 to 5 per 1,000 with a 90% certainty, it would require a sample size of 2,795 exposures to the compound at the critical time in pregnancy and a comparable group of non-exposed individuals. Thus, it is difficult to detect an increase in the incidence of a malformation in the human being and relate it to a single cause.

There have been a few other situations in the human experience that have presented some information on the fragility of the developing fetus. One of these was the use of the atomic bomb at Hiroshima and Nagasaki in Japan. The major developmental consequence of this radiation exposure was microcephaly and mental retardation [3,4].

Microcephaly and mental retardation have also been produced in animals upon radiation exposure of the embryo or fetus [5]. A very interesting finding of such studies was the potential mechanism by which the microcephaly and/or mental retardation were produced. Ionizing radiation selectively killed cells in the brain when they were dividing. Thus, whole generations of cells were eliminated from the brain during development. Pathologic investigations showed that in some sections of brains of irradiated rats the nerve cells were not in orderly patterns as expected, but displayed a random mixed-up order. It was not surprising to find that animals such as these had behavioral disorders and decreased learning capacity. These effects of radiation can take place during the period of organogenesis as well as the fetal period since refinement of the development of the nerve cells takes place after organogenesis. This period of fetal development is a very hazardous period to the developing organism even though anatomical malformations are not produced.

Effects on the fetus are often not detected until the newborn is examined. An example of this occurred in Japan in the late 1960's [6]. Some Japanese babies were born with dark brown coca-cola colored patches on their skin and were called cola-babies. They were part of a larger problem known as "Yusho" or rice-oil disease. Rice-oil was contaminated with tetrachlorobiphenyls (Kanechlor 400). This rice-oil was used for cooking so that the food was contaminated with tetrachlorobiphenyls. There were nine cola-babies available for study. Two were stillborn. The seven live born were underweight and small. Laboratory tests showed no abnormalities and the skin faded in color within a few months. Analysis of the skin disclosed the presence of the tetrachlorobiphenyls. Hopefully, follow-up studies of these children will be available soon.

Another incident of this type but much more extensive and severe occurred a number of years ago in Turkey when some wheat that was treated with the fungicide hexachlorobenzene was used for making bread instead of for agriculture purposes. The contaminated bread was eaten by many people in a number of villages.

The adults and juveniles displayed symptoms of hexachlorobenzene toxicity manifested mainly as porphyria, a disorder of porphyrin metabolism. Between 1955 and 1959, there were an estimated 3,000 cases of porphyria with a mortality rate of 10%. This does not include the disease called "pink sore" which affected infants of mothers that had porphyria or mothers that were exposed to hexachlorobenzene. Over 500 children were treated at one hospital and the incidence of mortality was excessively high which nearly eliminated all the children between the ages of two and five years [7,8,9].

There was also a very high incidence of stillbirths and early infant deaths. The cause of death was not known. The infants were probably born with deposits of hexachlorobenzene in their bodies; this was then compounded with the hexachlorobenzene that was demonstrated to be in the milk of the mothers. There have been a number of reports of pesticides and other environmental agents present in human milk. This is a food supply that cannot be readily monitored or regulated.

A separate incidence in France a few years ago showed that hexachlorobenzene could also be found in cow's milk. Cows were fed endives that were grown in a field treated with PCNB (pentachloronitrobenzene), another fungicide. Hexachlorobenzene was a contaminant in PCNB. The hexachlorobenzene accumulated in the endive; the cows ate the endive and the hexachlorobenzene was detected in the cow's milk [10].

To eliminate problems with hexachlorobenzene, it would be easy to restrict it from use as a fungicide. However, it has been shown in the last few years that hexachlorobenzene is a contaminant in a number of products other than PCNB. It is created during the manufacturing process of these other chemicals, carried throughout the entire procedure, and is present in the final product. It is very difficult to eliminate unwanted by-products such as hexachlorobenzene.

To further evaluate the potential problems that hexachlorobenzene might cause, some laboratory experiments were done in mice [11]. The mice were treated for 4 or 5 days during gestation with PCNB containing 10% hexachlorobenzene as shown in Table 2. The fetuses were removed and analyzed for pesticide content. It was very interesting to see that the fetuses accumulated hexachlorobenzene but not PCNB. After 4 doses, there were 4.9 ppm hexachlorobenzene in the fetuses. After the fifth dose, the fetal content rose to 7.9 ppm, almost doubling. The hexachlorobenzene was being deposited in the fetuses faster than they could eliminate it. The fetuses would be born with a large supply of hexachlorobenzene stored in their bodies. This is one example of an environmental agent that can adversely affect the development of human beings during both the fetal and neonatal periods.

TABLE 2. PREGNANT MICE TREATED WITH PCNB CONTAINING 10% HEXACHLOROBENZENE*

Daily dose	Fetal content, ppm	
	PCNB	Hexachlorobenzene
After 4	0.10	4.90
After 5	0.02	7.85

*From Courtney, K. D., Copeland, M., and Robbins, A., Tox. Appl. Pharmacol. 1975, in press.

There is another tragic example of neonatal problems arising from prenatal exposure to a compound that is more toxic to the fetus than the mother. This problem was first detected in the fishing village of Minamata, Japan [12]. Food contaminated with methylmercury produced methylmercury poisoning and this became known as Minamata Disease. Pregnant women did not readily display signs of Minamata Disease, but when the children were born, it was obvious that they had been exposed to the toxic properties of methylmercury as fetuses.

The children displayed symptoms similar to those seen in cerebral palsy. Gross anatomical malformations were not the problem as much as the central nervous system malfunctions. Animal studies have shown that methylmercury crosses the placenta readily and is preferentially deposited in the fetus especially the fetal brain [13]. Due to this preferential deposition, the mother was often spared from being affected. The children that have Minamata Disease will never recover and assume a normal life.

The experience at Minamata, Japan should have alerted the world to the problems that could be encountered with methylmercury poisoning. But in 1972, in Iraq, there was another epidemic. It was due to eating homemade bread from wheat that had been treated with methylmercury as a fungicide. Many infants showed the cerebral palsy-type symptoms indicating central nervous system damage. One small group of 15 infants and their mothers was available for long term extensive studies [14,15] and the following observations are quoted from the report:

1. Pregnancy: All infants were born at full term. No premature births in the group.
2. Delivery: In five cases the delivery was unduly prolonged.
3. Sex of newborn: There were eight males and seven females; a normal ratio.
4. Feeding: All infants were breast fed even though the mothers were advised not to.
5. Early neonatal period: No difficulty in sucking or swallowing. There was no cyanosis, jaundice, fever or convulsion.
6. Congenital malformations: There were none.
7. Weight and length: These parameters were normal.
8. Head circumference: Three of the infants had small heads.
9. Excessive crying: There were fretfulness, irritability and excessive crying in six infants.
10. Sight: Four infants were completely blind. One was partially blind. There was nystagmus in one infant and strabismus in two. The reaction of the pupil to light was absent in two cases.
11. Hearing: Four of the infants had severely impaired hearing.
12. Muscle tone: Muscle tone was increased in three infants and decreased in two.
13. Muscle power: Four infants had severe generalized paralysis.
14. Tendon reflexes: Five infants had hyperactive reflexes.
15. Mental powers: Four infants seemed to have decreased mental powers.

Three of the severely affected infants were exposed only in the last three months of gestation indicating that the third trimester might be the period when the human fetus was most sensitive to methylmercury poisoning. Although this study dealt with a small group of infants, many more were involved in the epidemic. Detailed data on the others are not available since most lived in rural areas which limited the number of cases that reached the hospitals and were available for study. Quite recently there have been similar outbreaks of methylmercury poisoning in Pakistan and Guatemala due to contaminated wheat being used for bread.

Methylmercury poisoning in infants presents a situation that is similar to cerebral palsy. Cerebral palsy is now considered to be just one group of a wide spectrum of defects and disorders resulting from damage to the brain before, during or after birth. This spectrum includes not only cerebral palsy but also mental retardation, epilepsy, sensory defects, learning and behavioral disorders and minimal brain dysfunction. When brain injury results in the inability to control muscles normally, the diagnosis of cerebral palsy is made.

This brain injury can result from many causes such as heredity, encephalitis, breech delivery, as well as irradiation, and anoxia. It is difficult to determine how many of the causes can be directly related to environmental agents. It is not known exactly how many individuals in the United States have cerebral palsy. The estimates range from 500,000 to 600,000 individuals. Three to six infants in every thousand have cerebral palsy which amounts to 10,000 to 20,000 babies per year. Cerebral palsy is one of the most common disabling problems of childhood [1].

Another postnatal problem that is quite prevalent in the United States is lead toxicity in young children [16]. It occurs in preschool age children that live in the older homes in large cities. These homes have many layers of old paint that have a high content of lead. This paint peels and flakes off and the children either eat the paint directly or get the paint on their hands and then put their hands in their mouths. The lead levels build up in their bodies and many suffer from lead poisoning. Signs of lead poisoning in these children are failure to grow and thrive, anemia, hyperactivity, porphyria and minimal brain dysfunction. Many of these signs have been noted before as manifestations of toxicity caused by other agents such as hexachlorobenzene [17,18].

Children with porphyria or other aspects of lead poisoning do poorly in school and have many social problems. The effects may not be entirely reversible upon removal of lead from their environment. Again it seems that the very young infant is more susceptible to lead poisoning than either older children or adults. The younger the infant, the more readily the lead affects the brain [19].

In the last 10 years, massive screening programs have been undertaken in the United States to detect children with high levels of lead in their blood. In 1971, 200,000 preschool age children in New York City were examined for lead toxicity and about 2,000 new cases were detected [20]. Attempts have been made to reduce the lead content of their environment.

The toxicity of lead had been known for a very long time. At the turn of the century, lead was used as a home remedy to induce abortions for unwanted pregnancies. Gilfillan, a sociologist, has put forth an interesting thesis that the fall of Rome was caused by lead toxicity [21]. The Romans stored wine in lead vessels. The acid nature of the wine leached the lead from the containers. It did not take long to poison a whole nation. Since lead causes infertility in both men and women and also causes abortions, stillbirths and postnatal maldevelopment, it can be considered that the Romans really drank themselves into extinction.

In this report, congenital malformations was not defined because there is lack of agreement on a precise definition. When a defect is severe, there is no debate on the issue. When the defect is a slight deviation from normal and does not influence the quality of life, then it is difficult to establish the limits of normal versus defective. However, one can adopt the definition put forth by the National Foundation which defines a birth defect as "a structural or metabolic disorder present at birth whether genetically determined or a result of environmental influence during fetal life" [1].

If only the more serious defects are considered, then it is estimated that about seven babies out of every 100 have a defect recognizable at birth. An additional 7% are detected by the end of the first year of life. It has been estimated that 1.4 million children are born every year throughout the world with one or more significant birth defects. Genetic disorders or viral infections can be the cause for many; but in over 50% of the cases, there is no known cause of the malformation. It is not known how many environmental agents might cause maldevelopment.

Thus far, a number of agents have been identified that affect the developing human being at various stages of development. The effects can be malformations, functional deviations, or death. These adverse effects attest that environmental agents are present in excessive amounts in relation to the developing organism. In the situations in which there has been damage to the developing human being by accidental exposure, the dose is usually unknown. Many attempts are made to arrive at a reasonable estimate. This is then compared to the known exposure levels of laboratory animals. Animals rarely respond to exactly the same dose levels as human beings or other animals. However, they each have a dose range in which they respond. By establishing enough of these dose ranges and comparing effective levels in both experimental animals and human beings, limits can be set on levels which would be considered excessive for developing organisms. The biggest problem that challenges the scientist is to achieve the ability to predict which compounds might present problems.

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THE PROBLEM OF COMPREHENSIVE EVALUATION OF THE DANGER OF THE EMERGENCE OF REMOTE CONSEQUENCES OF THE EFFECTS OF VARIOUS ENVIRONMENTAL FACTORS

N. F. IZMEROV and I. V. SANOTSKIY

STUDY OF THE REPRODUCTIVE FUNCTION UNDER THE EFFECT OF CHEMICAL AND PHYSICAL FACTORS

Chemistry and Ionizing Radiation

It is well known that under the conditions of production and in daily life many physical and chemical influences are combined. This occurs against the background of differing degrees of the balance of nutrition which in itself may be the cause of change in gonads and embryos, as well as against the background of the frequent use of medicines, many of which have an effect on the reproduction processes of subsequent generations. In most publications the idea of summation and the taking of algorithms of effects in the indicated cases predominates. However, the actual combinations of mutagenes may have different consequences.

Thus, for example, when studying the influence of caffeine on the reproductive ability of cells of Hela and the fibroblast-like cells of the Chinese hampster following x-ray irradiation there was demonstrated a decrease in the survival rate of cells by two to five times and a doubling of the number of aberrant anaphases [1]. On the other hand, under certain conditions the combined effect of ethylenimine and ionizing radiation decreased the mutagenic effectiveness [2]. A protective effect, given the combined influence of two mutagenic factors, has been described for the combined influence of x-rays with streptomycin [3], with nitrosomethyl carbimide [4], and for other combinations. A fundamental role is played by the intensities of the influence [5].

The Combined and Complex Effect of Chemical Mutagenes Can Also Have Ambiguous Results

A number of researchers have indicated that, for example, caffeine, while not causing chromosomal aberrations at the point of growth of legume roots and the somatic cells of the Chinese hampster, was capable of increasing the number of chromosomal rearrangements following the influence of mitomycin C, thio-TEF and others [6]. At the same time caffeine decreased the frequency of chromosomal aberrations induced by an alkylating compound — dipin — in the hepatocytes of rats [7], and did not increase the induction of dominant lethal mutations when combined with methylmethane sulfonate, TEF and others [2]. At the same time it was shown that the combined effect (in aqueous solution and simultaneously from the gas phase) of such supermutagenes as ethylenimine, dimethyl sulfate and nitrosomethyl carbamide led to a decrease in the frequency of mutations when compared with the effect of a single mutagene [8].

It is obvious, however, that when determining the danger of environmental factors, research conducted on mammals is of the greatest importance. Unfortunately there has not been enough of this research. For example, in animals subjected to a six month influence of formaldehyde in drinking water (at a concentration of 0.1, 0.01 and 0.005 mg/1 with a maximum permissible concentration [MPC] of 0.5 mg/1) and in the air (four hour exposure five days a week at concentrations of 0.5, 0.25 and 0.12 mg/m^3 with an MPC in the air of the work area of 0.5 mg/m^3), hystochemical disturbances in the testicles without an overall toxic effect were noted [2].

As a counterexample we cite the data of our Institute on the effect of tetramethylthiuram disulfide (TMTD) in its separate and complex ingestion in the stomach (with drinking water — 20.0 and 0.8 mg/1) and when inhaled (the MPC level — 0.8 mg/m^3).

V. N. Zhilenko [9] demonstrated that the complex influence of TMTD at sub-threshold levels (0.8 mg/1 with water and 0.9 mg/m^3 when inhaled), which were established in separate ingestion, caused an intensification of the overall toxic effect, judging from the functional changes in the composition of the red blood, the state of the nervous system and kidneys. At the same time there were no gonadotropic and mutagenic effects at the indicated levels either in the separate or the complex ingestion with water and air.

It should be recalled that, according to data of the literature, TMTD affects the reproductive function [10].

Thus, the question of the general laws of the combined and comprehensive effect of environmental factors [11-13] cannot be considered resolved if we proceed from specific types of effects.

CARDIOVASCULAR PATHOLOGY AS A REMOTE EFFECT OF THE COMPREHENSIVE INFLUENCE OF THE ENVIRONMENT

Cardiovascular pathology, as is known, is the leading cause of death of people in most countries and to a large extent determines the average life expectancy — one of the integral indices of social well-being. The explanation of the etiological role of chemical compounds in the development of cardiovascular disease (hypertension, athero- and arteriosclerosis, cardiosclerosis and so forth) is at present one of the most pressing problems of preventive toxicology.

The Nature of the Combined and Comprehensive Influence of Chemical, Physical and Social Factors Unfortunately Remains Unclear

As is known, lipoide infiltration of the vascular wall, being one of the preconditions of the development of arteriosclerosis, occurs when there is a nutritional imbalance (with a predominance of fats and carbohydrates). At the same time a number of chemical compounds (for example, CS_2) cause the depression of the activity of the lipolytic lipase of the vessel walls [2]. The combination of both of these features can probably lead to an intensification of the disruption of lipoide exchange with all the adverse consequences ensuing from it. Nevertheless at low levels of influence of CS_2 (MPC, Lim_{ch} this problem remains unstudied.

Emotional tension, an increased psychological load, "stress" situations in the work situation and in daily life are conducive to the development of hypertonic, ischemic disease, myocardial infarct, disruptions of brain and kidney blood circulation.

There are developments in the area of labor physiology, which suggest a division of labor according to the degree of emotional stress into several groups:

- —labor that is not emotionally stressing (work by instruction),
- —labor presuming personal material responsibility to moderate extents — labor with a moderate emotional load,
- —labor with an increased emotional load, which is connected with great material responsibility or risk of one's own life,
- —extremely tense emotional labor, connected with responsibility for the lives of other people [14].

Many types of labor in the modern chemical industry and other branches of the national economy, in which a person has contact with chemical compounds, may be ascribed to labor with an increased emotional load. Work with extremely dangerous toxic substances or explosives, of operators of complex technological processes and so forth could serve as an example of such a combination. However, the significance of this combination when the level of chemical influences is low (MPC, Lim_{ch}) remains unstudied.

The quantitative description of emotional tension is an obligatory prerequisite to comprehensive research. Most promising is the combination of clinic, epidemiology and experimentation.

Comprehensive Influence of Chemical Factors

In recent years it has been shown that some chemical compounds can cause specific changes in the heart and blood vessels at remote periods following influence at minimal concentrations. The indicated changes include the disruption of lipoide and protein exchange, the composition of the aortic connective tissue, morphological restructuring of the wall of vessels of the musculo-elastic type, myocardium, etc. [15-18,2].

A defect of the indicated studies is the absence of information on the overall toxic effect, or the correlation of the dose (concentration) of the harmful substance and the effect (with a determination of the thresholds), or the use of only high levels of influence, the results of which, as is known, do not coincide with the results of influence at a low level.

At our Institute, I. V. Sanotskiy, N. S. Abalina and N. S. Grodetskaya approached the problem from a different angle [19,20]. By a comprehensive method (nearly 20 indices were used) they studied the rate of "natural" aging of vessels, with the influence on experimental animals of a number of substances in small doses and concentrations.

In this regard the most harmful substances, as is known, are carbon disulfide, carbon monoxide, sodium fluoride, the salts of heavy metals and other compounds. Characteristic of many of them is the possibility of simultaneous ingestion in man's body by different means (with water, food, and air from the atmosphere and from the atmosphere and from the air of work places). Considering that with the comprehensive influence, the majority of chemical substances in minimal concentrations act according to the principle of summation (or the taking of algorithms) of the effect, the study of the state of the cardiovascular system under the conditions of the simultaneous ingestion of a poison by different means into the body of man and animals is of considerable interest on the level of public health limitation of the content of the above-indicated substances in the environment.

However, little such research is being performed. Preliminary data attest to the real (in some cases greater than when there is isolated ingestion) danger of the comprehensive influence of sodium fluoride, TMTD and several other compounds. According to the data of our Institute [2] with the isolated ingestion of sodium fluoride into the organism of experimental animals with water (male white rats) in doses close to the MPC for reservoir water (1.0 and 0.1 mg/kg) for a year a comprehensive evaluation was made of the state of the vascular system using functional (arterial pressure, permeability and stability of the capillaries of the skin, EKG), biochemical (level of chloresterol, β-lipoproteides, phospholipins, total protein in the serum, the amount of noncollagenic [in terms of hexosamines], collagenic [in terms of hydroxyproline] proteins and mucopolysaccharides [in terms of hexuronic acids] in the aorta wall) and morphological methods (the morphometric evaluation of the aorta and vessels of the musculo-elastic type). A change was shown in the lipoide and carbohydrate exchange in rats, as well as changes, characteristic for accelerated age dynamics, in the interstitial matter of the connective tissue of the aortic wall.

With the comprehensive ingestion of sodium fluoride with water and air (in concentrations at levels of the corresponding MPC's for reservoir water and the air of work areas) an intensification of the effect of the poison was shown, judging from the pathogenic indicators of fluoric intoxication. The disturbances of mineral and energy exchange, which are characteristics of fluorosis, as well as the disruption of neuroendocrine regulation of the vascular alveus, are the basis of and precondition for the development of the above-indicated remote consequences of the influence of fluorineion on the cardiovascular system.

The existence of natural and man-made geochemical provinces with an elevated concentration of sodium in the soil, water, plants and animals presumes the need to use a greater coefficient of reserve in the public health limitation of the content of the indicated compound in objects of the environment (the air of residential areas and the air of production installations, and others).

A researcher at our Institute, V. N. Zhilenko, obtained additional information on the nature of the comprehensive effect of tetramethylthiuram disulfide (TMTD), which attests to the possibility of intensification of the effect in the simultaneous ingestion of the poison in animal organisms with water and breathed air in the same doses and concentrations as NaF (that is, at a level of the MPC's established in isolation) [9]. The isolated ingestion of TMTD with water for 6 months in a concentration at the level of the MPC for reservoir water caused hypertrophy of the myocardium of the left ventricle, which was found upon morphometric evaluation of the myocardium (an increase in the average thickness of the myofibrils of the left ventricle of the heart through hyperplasia of endocellular elements). This may be the appearance of compensatory rearrangements connected with accelerated processes of aging of the myocardium. Dispersion analysis showed that the involvement of inhalation means of ingestion played a large role in the effect of summation; it is recommended to increase the coefficient of reserve when setting public health standards of TMTD in the air of the work area.

DIFFICULTIES IN STUDYING REMOTE EFFECTS IN THE COMPREHENSIVE EFFECT OF ENVIRONMENTAL FACTORS

Toxicity and nature of the effect changes with different means of ingestion of substances in an organism. For example, chloroprene, trifluoroperazin, morpholine and others are moderately toxic when ingested in the stomach and highly toxic when inhaled. Formaldehyde has an embryotropic effect on animals and a mutagenic effect on the fruit fly when ingested in the stomach, but does not cause these effects when inhaled [22,23].

The permissible level of content of substances in water and the air of residential areas and work areas should be harmless to the health of all age groups. Important in this regard is the question of age sensitivity. Information has been published on the higher sensitivity of the gonads of young individuals, for example, to the effect of certain pesticides (methylparathion, karbaril) [2]. In recent years an active study has been conducted on the transplacental induction of tumors, which attracts attention to the possibility of the comprehensive inducement of cancerogenesis.

The criteria and methods of evaluation should be adequate, yet this is not always the case. Use is still being made of "full-scale inoculations," for which the criteria of danger have not been established; frequently lacking is an analysis of the data from the viewpoint of their physiological fluctuations.

CONCLUSION

Only the combination of full-scale research with experimentation will make it possible to resolve the problems of the dependence of the pronouncement of remote effects on the dose of a chemical compound, to evaluate the diversity of combinations of various chemical compounds with no less diverse physical, alimentary and emotional loads. Mathematical elaboration will make it possible to draw a more substantiated conclusion on the actual role of chemical compounds and the various means of their ingestion in an organism in the development of remote pathology under the conditions of nervous-emotional tension, nutritional imbalance and the complementary influence of physical factors, as well as on the permissible loads of the indicated factors when the effect is comprehensive.

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THE DETECTION OF NATURALLY OCCURRING AND MAN-MADE CARCINOGENS AND MUTAGENS BY THE DNA REPAIR ASSAY

H. F. STICH, R. C. SAN, P. LAM, and D. J. KOROPATNICK

Detailed evaluation of chemical carcinogens and mutagens in man's environment is hampered by lack of analytical techniques sensitive enough to detect small quantities of chemicals in large bodies of water or air, and economic enough to be applied in large-scale monitoring programs. Chemical analyses, the apparent method of choice, are of only limited value at present. Primarily one must know the molecular structures of the compounds. But in many cases the chemical natures of the environmental carcinogens are unknown. As a second disadvantage, most chemical analyses require a great deal of time and costly instrumentation. Finally, the manpower and physical facilities are not available to initiate and maintain extensive national or global monitoring programs for chemical carcinogens and mutagens. These difficulties and dilemmas can be solved by applying biological indicator organisms that appear to be more relevant in assessing a hazard to man. The newly designed short-term test systems which may lead to a rapid advance in the field of environmental carcinogenesis and mutagenesis can be divided into three major groups: 1) tests using point mutations of micro-organisms (e.g., *S. typhimurium* [1], *E. coli* [2], plants *(Neorospora crassa)* [3] or invertebrates *(Drosophila)* [4]) as indicators of a mutagenic and carcinogenic capacity; 2) tests employing cultured mammalian cells (including human fibroblasts and lymphocytes) for measurement of an injury to cells by estimating a) fragmentation of DNA molecules [5,6], b) DNA repair synthesis [7,8], c) chromosome aberrations or d) neoplastic transformation [9] and 3) tests making use of "built-in" accumulator and indicator organisms which can be used in an early warning system [10, 11].

The feasibility of using DNA alterations (DNA fragmentation and DNA repair) in cultured human cells is best illustrated by a few examples. In judging these procedures one must keep in mind that a DNA repair or DNA fragmentation test can be completed within a week, with a minimum outlay of equipment and technical support. This advantage is in contrast to the 2 to 3 years and $150.00 per compound that are necessary when the "classical" rodent test for carcinogens is used.

Carcinogenic potential of *complex mixtures* can be revealed by shifts in sedimentation profiles of DNA released from cultured human fibroblasts. One example is shown in Figure 1. Extracts of

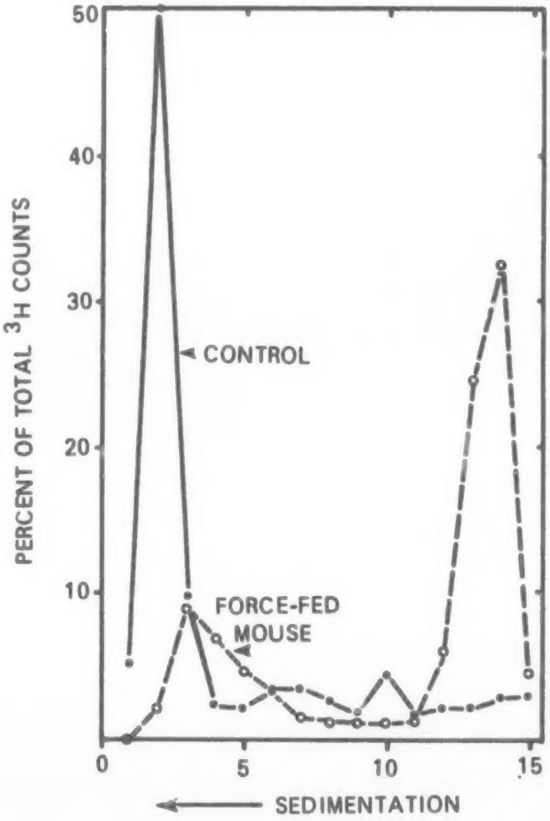

Figure 1. Sedimentation profile of ^{3}H-DNA released from ileum of Swiss mice force-fed on ethanol extracts of whole bracken fern *(Preridium aquilinum)*. Control ●——●; force-fed mouse ○——○.

bracken fern (*Pteridium aquilinum*), proven to be carcinogenic in rodents, [12] fragments the DNA of cultured human cells. The ease of detection of *industrial chemicals* can be seen in Figure 2. *Naturally occurring compounds* may also be assayed as potential mutagens. This approach is exemplified by examination of the products of ascorbic acid, [13] which are consumed in relatively large quantities and are added to many common foodstuffs, see Figure 3.

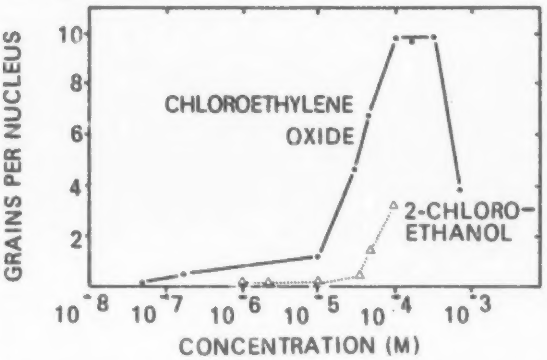

Figure 2. DNA repair synthesis in cultured human fibroblasts exposed for 2 hours to various concentrations of chloroethylene oxide or 2-chloroethanol.

One convenience of using human cells is the possibility of simulating conditions that prevail in man or within the human population. For example, the effect of *cancer predisposing genes* can be investigated by observing a decreased level of DNA repair synthesis [14], Figure 4, or an elevated sensitivity [15] to the lethal effect of carcinogens or mutagens, see Figure 5.

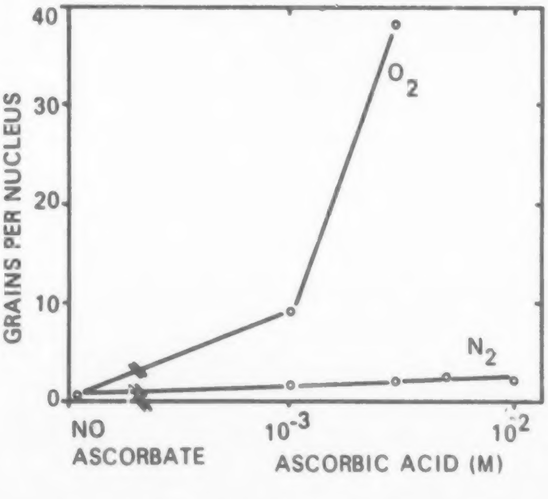

Figure 3. DNA repair synthesis in cultured human fibroblasts exposed to ascorbic acid in an O_2 or N_2 atmosphere.

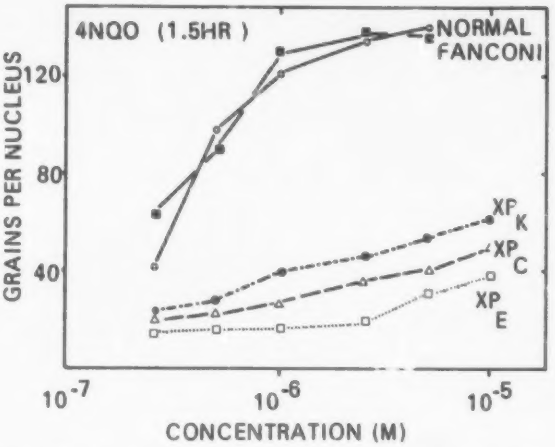

Figure 4. Reduced levels of DNA repair synthesis in cultured cells of Xeroderma pigmentosum patients. Cells were exposed for 1.5 hours to the carcinogen 4-nitroquinoline-1-oxide.

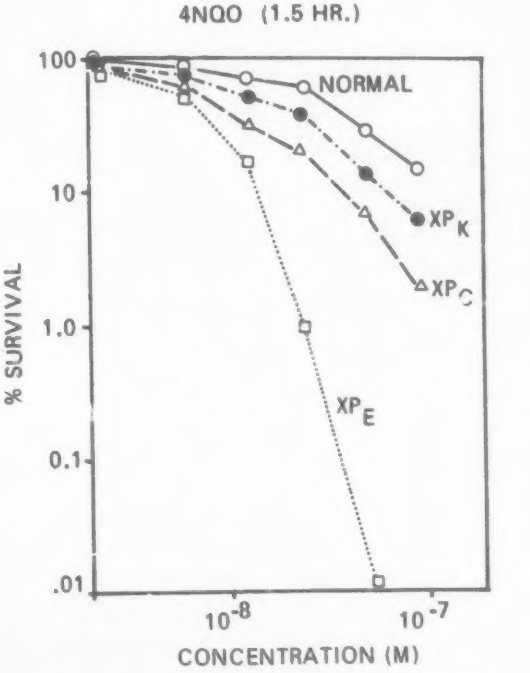

Figure 5. Clone-forming capacity of cultured Xeroderma pigmentosum cells following an exposure to 4-nitroquinoline-1-oxide.

Less well understood, but by no means less important, is the possible enhancement of the mutagenic and carcinogenic effect of oncogenic viruses in the presence of chemical carcinogens. A hitherto unknown phenomenon was discovered when the interaction between viruses, chemical carcinogens and cancer predisposing genes was examined. Figure 6 illustrates this pattern. Activated aflatoxin B_1 induces DNA lesions in human adenovirus type 12 (AD 12) which results in the activation of viral DNA and suppression of viral replication. In the cultured fibroblasts of normal persons the viral DNA lesions are repaired, the virus resumes replication and progresses finally to lysis of the infected host cell. On the other hand, no recovery of viral replication occurs in the repair-deficient cells of Xeroderma pigmentosum (XP) patients. The unrepaired viral DNA exerts a chromosome-breaking action in these cells without causing cell lysis. In other words, the application of aflatoxin B_1 to AD 12-infected normal cells leads to a complete replicative cycle and cell death, whereas an abortive replication cycle occurs in XP cells.

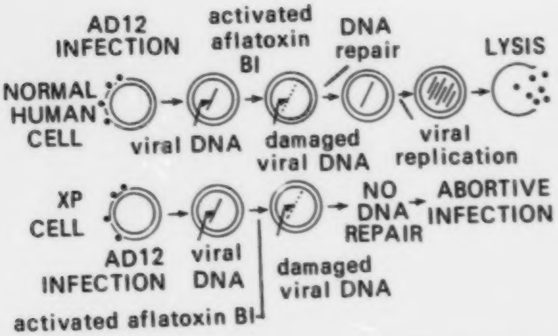

Figure 6. The interaction of oncogenic virus (adenovirus type 12), chemical carcinogen (activated aflatoxin B1), and cancer predisposing gene (Xeroderma pigmentosum).

The DNA repair test is also suitable for investigation of synergistic, enhancing or supressing effects if two or more chemical carcinogens or mutagens are jointly applied [16]. Such experiments may mimic the environmental exposure of man to several hazardous compounds at once. For example, ascorbic acid can suppress the repair of UV-induced DNA lesions, making cells highly sensitive to the lethal and mutagenic effects of this non-ionizing radiation. In this connection it should be noted that ascorbic acid as well as UV light are agents to which man and other organisms are daily exposed.

As a rule, the average man in an industrial society is not once, but repeatedly exposed to many small doses of carcinogens and mutagens. There are very few experiments that have examined the effect of sequential doses of chemical carcinogens on cultured cells. The small number of experiments that have been performed reveal that cultured cells cannot respond to a second dose of chemical with a new DNA repair synthesis within two to three hours following administration of the first dose [17]. In this "refractory" period following the inflection of DNA damage, the cells are highly sensitive to the lethal and mutagenic action of a second dose.

In this report we have shown the feasibility and adaptability of rapid and economic short-term assays that can be applied to cultured human cells, and should therefore provide results directly applicable to man.

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ORGANIZATION OF BIOSPHERE PRESERVES (STATIONS) IN THE USSR

I. P. GERASIMOV, YU. A. IZRAEL, and V. YE. SOKOLOV

The system of biosphere preserves (stations) is created to study, control and forecast the state of anthropogenic changes in the biosphere as the habitat of man. Biosphere preserves may become a component part of a global monitoring system (on a background level); they must, above all, ensure national interests. Therefore, the network of Soviet biosphere stations is a component part of a system of national monitoring, that is, an observation and control service for the natural environment of the USSR. The system is based on the national system of observation and control over the pollution levels of the air, water and land of the USSR Hydrometeorological Service and for monitoring the state of man's health, the appropriate service of the USSR Ministry of Health. In the first stage the system of biosphere stations will be an independent experimental subsystem within the framework of national monitoring.

TASKS OF THE BIOSPHERE STATIONS

- Conduct of permanent observations and determination of background indices (parameters) characterizing the current state of the biosphere and its anthropogenic changes.
- Conduct of permanent, periodic and irregular target studies of various ecosystems to develop scientifically based parameters for the control of the state of the environment and its significance to the health and well-being of man.
- Protection of natural ecosystems and the resources that support the life of plants and animals and the development of scientific bases of nature conservation measures (primarily for the system of natural preserves).

In connection with the first two tasks the system of biosphere preserves must more correctly be called the system of biosphere stations.

In addition to these basic tasks, the area of the biosphere stations will be employed for the conduct of various scientific studies for international projects, as well as for a study of the problems of the environment and the conservation of nature.

COMPOSITION OF THE WORK OF BIOSPHERE STATIONS

The fundamental direction of the scientific work of the biosphere stations must be the conduct of systematic observations over the elements of the current biosphere for the chemical, physical and biological indices for the purpose of a reliable establishment of periodic or controlled changes in it and the evaluation of the ecological values of these changes or their causes (particularly anthropogenic).

The composition of these indices must include the geophysical characteristics of solar radiation entering the atmosphere as well as the Earth's surface as the main energy base of all biosphere processes. They must also include the observations over the appearance of flows of radiation energy across the atmosphere. Apparently the main attention must be turned to the role of the growing pollution of the atmosphere as well as the direct effect of heat of man-made origin on the total energetics of the biosphere. An important value must be assigned in these studies to the effect of the man-made actions on the climate and particularly on the gas content of the atmosphere, the consideration of the use of oxygen and the excretion of CO_2 as a result of the consumption of fuel, a change in the process of its photosynthesis, and so forth.

A special section must be composed of observations of the global water balance and the humidity circulation. Here, just as important is the reliable base-line of the man-made changes, as well as the forecasts for the future. The subjects of the study and observation must also include the man-made transformations of the cycles of the most important chemical elements (N, P, K, and others) with an obligatory inclusion in the study of the soil cover.

The list of media and indices subject to measurement and study include primarily:

- Air — carbon dioxide (CO_2) (in the air point and column), carbon monoxide (CO), sulfur dioxide (SO_2), nitric oxide (NO_x), ozone (O_3), (at the source in the air, in the upper atmosphere), dust, radioactivity, transparency of the atmosphere.

- —Surface waters, precipitation, ocean water (the latter for ocean stations) — mineral composition, heavy metals, petroleum products, pesticides, polychlorbiphenyls.
- —Soil, biota — microelements, pesticides, microbiological admixtures.

The scope of the basic tasks of the research studies at the biosphere stations must include a study of various ecosystems on land and in the oceans and those changes in the abiotic and biotic components of the ecosystem, brought on as a result of man-made changes.

Study of the biotic components (*biota*) must be conducted on an ecosystem basis (composition of the biota and its changes, functional vitality and biological productivity), dynamics of the populations of the indicator species, physiological form (photosynthesis respiration, growth, propagation) and molecular-genetic (mutagenesis, teratogenesis, and others) levels. It must be closely linked to a study of the abiotic factors (radiation balance, heat and water regimes) of the ecosystem and the nature of the anthropogenic factors affecting them (use of natural resources, pollution of the environment and others).

The conduct of geophysical, geochemical and biological studies and observations must be integrated by way of finding and describing the common balances of internal flows of energy and matter in the ecosystems under study, as well as their man-made transformation.

Thus, comprehensive studies both of external factors of the environment and the internal processes and phenomena occurring in the ecosystems must be carried out at the biosphere stations. Moreover, in order to find the man-made changes of these factors, processes and phenomena, studies must be carried out both of natural and to a greater or lesser degree of objects transformed under the influence of man, and appropriate experimental studies are also planned.

In addition to the basic tasks of determining the background indices describing the present state of the biosphere on a global scale, of great significance in accelerating the implementation of the results of these observations will be the close ties of the subsystem of biosphere stations with the national monitoring system and the scientific assessment of various types of economic activity from the point of view of their effect on the biosphere.

STRUCTURE OF THE BIOSPHERE STATIONS AND WORK METHODS

Proceeding from the above-mentioned data, each biosphere station must have a zoned structure for their territory with the allocation of the following basic zones — *central* (at the level of a global background)* showing the least changed natural ecosystems and where the strictest methods are employed for their protection; a *buffer* (transitory) where under scientific control various forms of land use are carried out and experimented with and comparisons are conducted on the state of the biosphere under the influence of the activity of man with the background state, and (possibly) *educational and demonstrational* where visitors would be allowed.

In the central zones of the biosphere stations the main purpose of the observations and studies must be the background characteristics and the natural bioproduction process (radiation energy, atmospheric and soil moisture, nutritive elements and others), trophic links (biological circuits and their disturbance); in the buffer zones the characteristics of the degree of utilization of natural resources in natural-technical ecosystems above all for the production of the biomass as well as the effectiveness of the methods for the control of the processes of the use of the natural environment and resources, from the point of view of the protection and improvement of the environment for the life and work of man.

In order to obtain general background characteristics of the biosphere use will also be made of sampling methods, including satellites, in addition to the above-mentioned observations.

APPROXIMATE DESIGN OF THE NETWORK OF SOVIET BIOSPHERE STATIONS

The total number of biosphere stations in the USSR need not be great. Initially their number will be limited to six with a subsequent increase. Of these five will be on land and one on the water. The following may be suggested as continental biosphere stations:

- —Arctic — located on Franz Josef Land. This biosphere station can be set up on the base of the Observatory im. Krenkel' of the Hydrometeorological Service on Kheysa Island. Rocket soundings of the upper atmosphere for a study of its background composition can be carried out from this base.
- —Central Forest Steppe — located in the geographic center of the European territory of the Soviet Union. This biosphere station must be formed on the area of the Kursk Field Base of the Institute of Geography of the USSR Academy of Sciences and the Central Black Earth Preserve. Scientific research has

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*This zone must be no closer to sources of anthropogenic impact than 50 to 100 km.

been conducted on this territory over many years and they will, to a substantial degree, correspond to the above-mentioned program; in addition, this territory is used as an aerospace range for the study of the natural environment and its resources following a Soviet-American agreement.

—Central Asian Desert — located in the sands of the Karakum and set up on the base of the Repetekiskiy Station of the Institute of Deserts of the Turkmen Academy of Sciences. Scientific research has also been carried out for many years on the territory of this biosphere preserve partially corresponding to the above-presented program.

—South Siberian Tayga — located on the territory of the Baykal preserve and the areas adjacent to it where a variety of scientific studies are being carried out with the active participation of the Institute of Limnology and the Institute of the Geography of Siberia and the Far Eastern Siberian Branch of the USSR Academy of Sciences.

—East Siberian Tayga — located in central Yakutiya near the pole of cold for Eurasia. This biosphere preserve can be established with the active participation of the Institute of Geocryology of the Siberian Branch of the USSR Academy of Sciences.

—The Ocean biosphere preserve can be composed of the ocean station within the system of the North Atlantic meteorological stations serviced by the scientific research ships of the Hydrometeorological Service.

In order to compare the state of the biosphere against the background level and the level of the existing impact of man, it is necessary to select around each biosphere preserve a representative network of test sites where it will be possible to assess in a complex manner the man-made changes in the environment (taking into consideration the direction and intensity of the processes) and in a number of cases to conduct purposeful experiments.

The Central Forest Steppe biosphere preserve has a wealth of opportunities in the selection of such sites since it is in the proximity of the Kursk Magnetic Anomaly and the chemical enterprises of the city of Belgorod as well as vast agricultural complexes.

The Central Asian Desert biosphere preserve has within 80 km to the east the city of Chardzhou with a developing petrochemical industry, other enterprises and developed oasis agriculture with the intensive application of fertilizers and various pesticides.

The South Siberian Tayga biosphere preserve is situated near wood chemistry complexes and the Cheremkhovskiy Coal Basin the area of influence of which will provide extremely important data on the degree of man's impact on the environment.

The East Siberian Tayga biosphere is near the city of Yakutsk and a number of mining enterprises.

In addition to this initial system of Soviet biosphere preserves it is proposed to establish a scientific-methodological research-station on problems of biosphere monitoring near Moscow in the area of Pushchino and the Prioksk-terrace preserve. In organizing scientific studies this station can rely on the scientific institutes of the USSR Academy of Sciences located in Pushchino and specifically the Institute of Soil Science and Agrochemistry of the USSR Academy of Sciences.

Implementation of the proposed plan for the development of biosphere preserves will aid in the solution of a number of scientific-methodological problems facing the national and the planned global systems for monitoring the state of the biosphere, assess its existing global background state, and determine the tendencies in changes of this state in the future.

THEORETICAL FOUNDATIONS OF GLOBAL ECOLOGICAL FORECASTING

S. S. SHVARTS

Human activity has a progressive effect on nature. It is beyond doubt that any precautionary measures (which are absolutely necessary) and any degree of improvement of production (closed cycles, and so on) will only reduce the effect of man on nature, but will not eliminate the danger of deterioration of the natural environment, if only for the reason that the most efficient production removes from biological circulation vast land and water areas. This should be evident to any person who is not inclined to overconfidence. But from this it by no means follows that mankind should pursue a policy of curtailing production. The thesis "back to nature" was always reactionary, the struggle to raise the living conditions of people requires the unceasing development of industrialization and urbanization.

However, there are no serious reasons to assume that man's influence on the biosphere and on individual ecosystems leads, with the inevitability of a law, to the deterioration of "nature." In order to get to the bottom of this fundamental question we must attempt to understand what is a "good" ecosystem and what is a "bad" ecosystem. It is always difficult to answer such a question, although intuitively we all understand "what is good and what is bad." Nevertheless, upon first approximation we can answer the posed question. A "good" biogeocenosis should meet the following requirements.

- —The output (biomass) of all the basic links of the trophic chains is high. The excess of phytomass over zoomass, which is characteristic of man-made landscapes, is not sharply pronounced. This ensures a synthesis of a large amount of oxygen and the synthesis of a large number of products not only of vegetable, but also of animal origin.
- —High productivity corresponds to high output. The product "productivity and biomass" approaches a maximum. This creates the prerequisites for rapid compensation of the possible losses of biomass at the individual trophic levels as a result of random or regular external influences. This circumstance is especially important. High output does not guarantee high compensatory activity of biological systems.
- —The structure of the system as a whole and the heterogeneity of the individual trophic levels ensure great stability of the ecosystem, given a broad range of external conditions. Greater efficiency of homeostatic reactions is characteristic not only of populations of dominant species, but also of the ecosystem as a whole. The maintenance of the ecosystem in a state of dynamic equilibrium ensures a state of homeostasis of the nonliving components of the ecosystem, including the hydrological regime of the territory and the gas composition of the atmosphere.
- —Metabolism and energy exchange occur at a high rate. The processes of reduction ensure the involvement in biological circulation of the entire biomass produced by the ecosystem in the course of a few annual cycles. This ensures the maximum rate of biological self-purification of the system.
- —A higher degree of productivity and stability of an ecosystem entails higher "reserve activity" — the capacity for rapid reorganization of the structure of the community and for rapid evolutionary transformations of the populations of dominant species. This ensures maintenance of the ecosystem in the optimal state given a change in environmental conditions.

If the ecosystem satisfies the listed requirements, there are grounds to consider it "good," regardless of whether it develops in a "natural" urbanized environment. Hence it follows that the long-term task of global ecology consists in developing measures that facilitate the development of "good" ecosystems under the conditions of a man-made landscape. On the other hand, the viewpoint being developed makes it possible to approach quite objectively the evaluation of the permissible load on the environment. If an ecosystem is capable in a man-made environment of maintaining itself (as a system) in an optimal state, this means that the degree of man-made influence does not exceed the potentials of biological systems, does not undermine their capacity for homeostasis. There are formidable theoretical grounds to assume that such a system of evaluations in practice coincides with public health evaluations. The state of the ecosystem is a more sensitive indicator of the environment than any other.

The analysis of the question posed in such an unusual form for the biologist ("What is good and what is bad") makes it possible to assert that some of the general changes introduced by industrialization can be regarded as a factor potentially conducive to the development of the biosphere. The increase in the content of CO_2 in the atmosphere creates the prerequisites for the formation of communities of increased productivity, which have an increased capacity for self-purification. Human activity sharply increases the energy exchange in ecological systems, which facilitates the overall rejuvenation of the biosphere, accelerates the evolutionary process and creates objective conditions for the development of flourishing ecosystems. Many (although, unfortunately, far from all) operations on the irrigation of deserts, land reclamation, the draining of swamps, and the eradication of epizooties "work" in this same direction.

We will not have the opportunity to go into the specific details of this question. However, it is important to emphasize that they force us to alter as well the manner of raising the basic problem of modern global ecology: are the "deterioration" of the natural environment and the collapse of ecological equilibrium an inevitable consequence of the overall strategy of development of industrial society, or are they the result of errors in technical policy?

In the process of evolution of organisms radical changes inevitably occur in the structure and energetics of ecosystems and the biosphere as a whole. Of particular significance are the various means of biological progress. Their diversity (any species of animals or plants is biologically unique, and chooses its own means of coping with the environment) for a long time served as a unique psychological barrier to the correct evaluation of the role of different groups of organisms in energetics and the functioning of ecosystems.

Even at the stage of "prelife" its development was determined by natural selection. The complication of macromolecules inevitably led to enlargement of the first organisms. This tendency in evolution continued even further: Morphophysiological progress was accompanied by an increase in body dimensions. This morphological law of evolution has grave ecological consequences. The most important of them is the reduction in the number of individuals in the population. The number of individuals in natural populations of bacteria is defined by astronomical magnitudes, the populations of insects number in the billions of individuals, those of rodents in the thousands and millions, of large predators in the hundreds and thousands. In correspondence with this the density of populations of different animals also changes. The smaller the body dimensions of an organism, the more numerous are its populations. The reasons for this ecological law are understandable: The larger an animal is, the fewer the individuals that can feed on a specific section of the living area. Hence it follows that morphophysiological progress should inevitably be accompanied by the emergence of mechanisms that insure relatively small populations given an extremely unfavorable combination of external factors. This "insurance" could follow two fundamentally different lines: the increase of individual and population durability.

In the early stages of the evolution of organisms "population durability" was able to be maintained through the colossal size of populations. At this stage a population might have been a primitive system, such as it seems to some theoreticians interested in biological problems. The inevitable consequence of morphophysiological progress — the reduction in size of populations — leads to the evolutionary inevitability of the improvement of a population as a system. The universal means of solving this problem was the reproduction process, which guaranteed the emergence and maintenance of the genetic heterogeneity of the population. In the process of evolution a well-known law of cybernetics, Ashby's law, is realized: systems consisting of a large number of heterogeneous elements are less subject to fluctuations.

However, the heterogeneity of a population is maintained not only by genetic but also by ecological elements. In this respect, animals of different levels of morphophysiological organization differ substantially. Greater physiological perfection requires improved homeostasis, not only as a state, but also as a process; it requires not only a constancy of the internal environment, but also a constancy of the course of ontogeny. For illustration let us compare representatives of a single class — mammals, rodents and carnivora. Mouse-like rodents are capable of passing through the full cycle of development under extremely different conditions (seasonal generations) and of substantially altering the rate of ontogeny. In conformity with this their populations consist of many ecologically unique groupings of animals differing in the rate of growth and development, in the demand on the quality and quantity of food, reaction to a change in the most important factors of the environment, and so on. The successful ontogeny of a predator is possible only in a relatively narrow range of external conditions. The structure of populations of predators is immeasurably simpler than that of populations of rodents. Therefore, in spite of the fact that the individual durability of predators is greater than the individual durability of rodents, the resistance of their populations to external influences proves to be immeasurably lower. The field mouse population cannot be exterminated, the tiger population needs to be protected! This example illustrates an important law: evolution was realized in two basic ways — by morphophysiological progress and by improving the organization of the population. The deep-seated processes at the basis of this law can be understood by comparing phylogenetically more distant organisms. Let us compare mammals with poikilitic vertebrates.

It is well known that the rate of ontogeny of cold-blooded animals (even when their temperature is comparable to the body temperature of birds and mammals) is considerably lower than that of warm-blooded animals. The rate of sexual maturation of the white sturgeon is many times lower than that of mammals of equal or even greater size. The white sturgeon becomes sexually mature in the 15th year of life, the white whale in the 5th year. The frog matures in the 3rd or 4th year, the field mouse, which is equal to it in weight, in the 3rd or 4th month. From the positions developed here this fundamental ecological difference between cold-blooded and warm-blooded vertebrates has a natural explanation which works with respect to any specific species.

The main weapon in the struggle for life of higher animals is morphophysiological improvement. Therefore, a population should reduce the infancy period of the individuals forming it, the period of formation of morphological improvement. For lower organized animals the situation is different; the durability of a species is determined by the improvement of its population structure. The longer the maturation period of animals (more precisely, the greater the range of mutability of the duration of ontogeny) and the longer the period preceding maturation, the greater the possibilities are for complication of population structures, especially when the different age stages are distinguished by substantial ecological features. For flourishing forms of "lower" animals this is precisely what happens. It is sufficient to compare larvae and adults for many insects and amphibians. When the different age stages of a species occupy in the ecosystem different niches, the possibility of a species becoming extinct owing to "random" change in the environment is reduced to a minimum. The dynamics of the number of tadpoles and adult frogs is subject to diametrically opposed laws. These are extreme expressions of a very general law: the greater the ecological diversity of the age stages of an animal, the greater the population's capacity to resist an adverse combination of external factors. It becomes comprehensible that in conformity with the two main lines of biological progress it is advantageous for "lower" animals to lengthen the period of development and for "higher" ones to reduce it.

The possibility of achieving biological progress in fundamentally different ways (on the levels of the organism and the population) to a considerable extent determines the structure of the ecosystem. In the groups of organisms examined the same ecological task is resolved in different ways. In correspondence with this their role in the life of the ecosystem is also different.

The need to maintain the metabolism level at a constantly high level made it necessary to expend a large amount of energy not on the building of tissues of the body itself, but on maintaining the optimal physiological state. A lion weighing 200 kg requires six to seven times more food than a crocodile weighing just as much. Small mammals and birds expend more than 95% of their energy on maintaining a constant body temperature. These seemingly special physiological characteristics of mammals and birds caused a revolution in the structure of the biosphere.

The rate of energy transformation in communities increased many times, while the efficiency of ecosystems decreased sharply. In ancient ecosystems the biomass of plants exceeded the biomass of animals only by four to five times, and no less than 15% of the output of the lower levels of the food chains passed to the upper levels. In communities of the new type the biomass of plants exceeds the biomass of animals by tens and hundreds (at times thousands) of times, yet the coefficient of efficiency of the community does not exceed 2 to 3%, but the rate of transformation of matter and energy has increased by tens of times. At the same time, the appearance of warm-blooded animals facilitated the establishment of direct biological channels between the ecosystems of various regions of earth, and fused the biosphere into a single whole. It would be possible to cite specific examples which demonstrate that ecological events developing in the Arctic to a significant degree determine the course of the most important ecological processes in the tropics.

Higher animals were powerful catalyzers of ecological processes. Converting a massive quantity of raw plant mass into materials easily assimilated by plants, higher vertebrates created the conditions for the development of highly fertile soils. At the same time there began the flourishing of higher insects — the pollinators of flowering plants. This led to intensification of the biochemical evolution of plants, the creation of forms which were characterized by an increased content of proteins and lipoid substances. This, in turn, promoted an increase in soil fertility. Worthy of attention is the fact that as a result of the evolution of higher vertebrates, higher insects and more advanced groups of plants on earth there appeared steppe and prairie areas, and soils emerged which were characterized by greater fertility.

In the plan of our topic it is important to emphasize the following. The appearance on earth of higher organisms led to the flourishing of the biosphere. Yet, at the same time, the morphophysiological progress of animals had as a consequence a decrease in the efficiency of the work nearly on an order of magnitude. This could easily be appraised as a sharp deterioration in the working of ecological systems. But as evolution continued, it was also accompanied by evolutionary changes of the ecological systems, as a result of which ecological systems of a new type emerged.

There are grounds to assume that the changes in environmental conditions caused by man's activity will also have as a consequence the adaptive evolution of both organisms and their complexes.

The ecological crisis consists not only in the fact that as a result of unreasoned actions of man, biological natural resources are perishing, but also in the fact that the capacity of natural complexes for self-regulation is being undermined or the system of self-regulation "works" against man and mankind. Hence it follows that the problem "man and the biosphere" above all should be resolved on the plane of creating the conditions for the development of the biosphere in a direction favorable for man.

Industry pollutes the atmosphere, the soil and water with substances harmful to everything living, upsets the thermal balance established in individual sections of the arena of life, increases the content of CO_2 in the atmosphere, threatens the integrity of the ozone screen, and removes from biological circulation greater and greater amounts of land (no less than several thousands of hectares a day). It changes the reflective ability of the earth's surface and facilitates the development of a desert climate. This list could be continued without end. Modern industrial society indeed is introducing and, what is most important, cannot but introduce all these disturbances into the biosphere. The progress of human society requires the development of industry, and the technophobia detected in many articles in defense of nature (as if nature needs to be protected, and not we, people) frequently turns into indifference toward the fate of people. However, if we exclude from our list (or an analogous, more detailed and lengthy one) the disturbances connected not with the technical strategy of modern society, but with the errors in technical policy and technical practice, this list would be shorter and more meaningful.

In untamed nature the processes of production predominated over destruction, ecological systems became more complex, more productive and stable; the degree of heterogeneity within individual ecosystems and the degree of heterogeneity of the ecological cover of the earth continually increased (biosphere — organized heterogeneity).

In an urbanized environment the situation changes substantially.

Ecological systems become simpler, "rejuvenate." A significant portion of energy and oxygen is expended on restoring disturbed ecosystems, on the processes of destruction of hard-to-disperse substances, the exchange of matter and energy slows down. The efficiency of atmospheric homeostasis decreases. Flora and fauna distinction between biogeographic regions are erased, endemic plants and animals to an ever increasing extent are replaced by cosmopolitans, new endemic plants and animals — those of technogenic landscapes emerge, the number of species having an elevated resistance to poisons, medicines, and so on continually increases. The biological "communications channels" between continents and biogeographic regions are being supplemented by technogenic ones. Cases attesting to a disturbance of the natural balance maintained by the biosphere for millions of years should not be regarded as the breakdown of a complex mechanism. If during the Cretaceous period, at the very height to the change of "kingdoms" — from the kingdom of reptiles to the kingdom of mammal birds — there had been an intelligent outside observer, he would have undoubtedly noted the decline in the ecological efficiency of the ecosystems of the earth and fully well might have regarded this as the degradation, the deterioration of the biosphere. This would be a mistake. Such a mistake is the attempt to reduce the changes occurring before our eyes in the degradation of the biosphere. Naturally, the poisoning of a river or the introduction of poisonous substances into the soil will destroy nature. But these and similar actions, no matter how widespread they are, cannot be regarded as an expression of the strategy of man of industrial society in nature; it is a deviation from the optimal technical policy. There are grounds to regard the changes in nature which were discussed above as a reaction of life in response to the changing conditions of the environment.

The simplification of ecosystems, their rejuvenation, the change in the structure of individual links of the food chains, the enhancement of the role of animals as the destroyers of primary organic matter — all these are not the simple degradation of the biosphere, but its evolution under new conditions.

Yet not all of these changes could a-priori be considered undesirable. They lead to an increase in biological stability and create conditions for utilizing the elevated concentration of CO_2 in the atmosphere. Moreover, the new, rejuvenated ecosystems lacking the internal coordination characteristic of ancient communities, are distinguished by a lesser degree of "closure," they affect the biosphere as a whole to a greater extent.

These conclusions, which at present are based on a large number of facts, should form the basis of ecological forecasting. At the same time it cannot be doubted that as a "new biosphere" emerges, in whose development a leading role is played by human activity, narrowly specialized species will decrease in number, and species distinguished by great ecological plasticity will increase. It could be demonstrated that even now in vast areas of land and water inhabited by ecologically representative species several species predominate — ubiquists which fulfill a leading role in maintaining the natural balance. From this it follows that in the functioning of the modern biosphere population mechanisms of maintaining ecological equilibrium play a more significant role than in "untouched" nature. This also determines the main directions of scientific research and the search for means to practically realize them.

The notion of evolution of the biosphere under new conditions as the main factor in the formation of the environment forces us to raise anew the question of the interrelationships of man and nature. Man should not assume the functions of the biosphere, but should lighten its work load. I would risk saying that the relationship of man to nature should be based on trust.

This idea may be illustrated fully by a specific example.

The water conservation and climatic role of forests was evaluated long ago. Even the most aggressive technocrats recognize that contraction of the forests would threaten catastrophe. The shallowing of rivers jeopardizes the centers of world culture and industry. But, forests continue and will continue to be felled. The solution is to plant forests. Their benefit is beyond doubt; they stabilize the atmospheric and hydrological regime of vast territories, and even modest gardens and parks decrease the dust content of the atmosphere by 40%. The benefit is beyond doubt, the scope of work is immense. The total area of protective plantings (including green zones of cities) is approximately equal to the forest area of Western Siberia. If we add to this the fact that urbanization is almost everywhere accompanied by the conversion of natural vegetation into forests of the park type, it will become evident that man-made forests in area, but not in their biological essence, are becoming commensurable with natural forests. They lack the main feature of natural forest ecosystems — the capacity for self-development and self-protection.

All work on creating artificial forests to a significant extent reflected the strength and weakness of technical thought that placed itself above nature. If we cannot do without trees, we will assume all the work and will resolve the biological problem by strictly technical means. As a result, the expenditures on replenishing and maintaining plantings are in the billions of rubles. But, after all, another means is possible: the cooperation of nature in creating specialized forest ecosystems in an environment changed by man. The unification of the efforts of nature and man will accelerate the process of creating productive and stable ecosystems in a changed environment.

Observations of the change in individual species of animals and plants and their complexes attest to the reality of the posed task. It seems to us that its complexity is exaggerated, which is clearly reflected by the underestimation of the adaptive potentials of individual species and their complexes. Suffice it to say that the populations of some species of plants in a few generations acquire a genetically consolidated capacity to create productive and stable populations -- and do so not in a simply adverse, but poisonous environment (for example, on lands rich in lead, copper and nickel, and, moreover, with a clear deficiency in calcium and phosphorous). Entirely possible is the formation of communities functioning as specific "neutralizers" of potentially dangerous industrial wastes, including radionuclides. Well known among bacteria are "oil destroyers," the effectiveness of whose work increases in the presence of vanadium. The creation of strains of bacteria and fungi, which effectively decay wood, would mean fundamental progress in the practice of timber rafting, a problem which is the present scourge of a number of production units. Since the detailed analysis of this question is not a part of our task, we will limit ourselves to but one example. Nicotine is a terrible poison. But after all, tobacco plantings need special protection from specialized species of insects. This clearly demonstrates that there are no fundamental limits for the development of productive communities in a unique environment. Naturally, in a different environment (upon first approximation, in different biomes) the direction of work should be different, but the notion of a unity of the biosphere should be their common trait. Worthy of special attention here are regions whose biological output is insignificant — polar territories, deserts, high mountains. Thus far the interest in these regions, apart from purely theoretical interest, has been determined by the possibility of deriving "benefits." The notion of a unity of the biosphere makes it possible to see in these regions, which constitute about 40% of the dry land, a vast reserve of biological productivity. Here once again there is needed a psychological breakdown in the consciousness of man armed with modern equipment. The obtainment from the indicated territories of immediately useful products is possible, but economically is not always profitable. However, the overall increase in the productivity that offsets the overall decrease in biological productivity on highly urbanized territories, which normalizes the regime of the atmosphere and hydrosphere of the planet as a whole, is quite possible at the present stage of development of technology. We have no room here to dwell on the impending technical and economic difficulties. But the now available experience shows that they are significantly less than those which are connected with the construction of major electric power stations and similar facilities.

The development of a system of measures in the above-indicated plan requires the development of a system of observations on the changes occurring in nature under the influence of man-made factors. Of course, this system should be based on public health norms. Taking into consideration, however, that the same factor (in its qualitative and quantitative expression) has a varying effect on man depending on the constellation of attendant natural conditions, an independent significance should be given to ecological monitoring. The size of individual species and their state, as an indicator of environmental conditions, are successfully being used at present (the content of chemical substances in different tissues of organisms at different levels of trophic chains; the rate of growth of trees, the energy of photosynthesis, the microbiological activity of soils; the growth of lichens, the development of various species of hydrobiota, and so on). It is advisable to supplement this system of regulation of the state of the environment with observations on a change in the structure of ecosystems, their spatial and functional interrelationships. Of particular importance is the analysis of ecological homeostasis given a simplification of individual trophic levels which involve or do not involve an overall decrease in the biological productivity of biosystems.

The analysis of the main trends in the development of the biosphere and of the attitudes of man toward the problems of the biosphere makes it possible to make a very general ecological forecast for the immediate decades. If we digress from the details, this forecast can be formulated in a few words:

A significant change in the structure of the ecosystem of the earth. An increase in the role of population processes in maintaining ecological equilibrium. The development of specific ecosystems of man-made landscapes, which are capable of self-renewal and self-regulation and are related by increased stability and an increased capacity for biological purification. On territories permitting only limited man-made development, the development of biogeocenoses which are distinguished by increased biological productivity. Maintenance of the general balance of the atmosphere at a level ensuring the optimal development of human society.

To resolve this task there must be the incorporation of ecological expertise in industrial and agricultural production and the incorporation of good industrial operations in the practice of the use of nature. The passive "protection of nature" is being replaced by work on creating the optimal natural environment, on the creation of ecosystems capable of self-regulation in an environment changed by man.

THE PROBLEM OF THE MAXIMUM PERMISSIBLE EFFECTS OF THE ANTHROPOGENIC FACTOR FROM THE ECOLOGIST'S VIEWPOINT

V. D. FEDOROV

THE PROBLEM

" 'Here we have a firm rule,' the Little Prince later told me.

" 'I got up early in the morning, washed, got myself in order, and at once set about putting my planet in order' " (p. 20).*

But the planet of the Little Prince "was only a bit larger than himself" (ibid., p. 18) and to keep it in order, it was enough for him to root out the baobabs and to clean out the volcanoes so that they burned quietly, without any eruptions.

Of course, for us, the people of Earth, it is much more difficult to keep our planet in order than it was for the Little Prince. And this is explained not so much by the incomparably greater dimensions of the Earth as compared to asteroid B-612, as by the absence of a single view on the order of things among the numerous inhabitants of our planet. In the age of the social disorder, the world's people, for direct advantage, began to sacrifice the natural wealths which could not be replaced. Thereby people placed themselves "outside general ecology," so that the consequences of their actions began to threaten the existence of man as a biological species. At the same time, the forms and scopes of human activity became an important ecological factor that transformed the face of the biosphere, as a consequence of which further biological evolution became directly dependent on the uncontrollable consequences of technical progress.

It is practically impossible in a single address to examine, even superficially, the numerous aspects of the problem of the interaction of nature and man, the problem of the place and transforming role of man in the biosphere. Some of the questions connected with the sphere of inhabitation concern the sinister consequences of the reasonable actions which were undertaken in the biosphere by man without sufficient consideration of their indirect or distant consequences. One of these problems is the problem of waste products, the most important aspect of which is the determination of the effects which waste products have on the productivity and future of biosystems. All the subsequent parts of this article are devoted to the discussion of this major problem.

THE PRODUCTION OF "WASTE PRODUCTS" AS A BIOSPHERE PROCESS

In the biosphere, processes connected with life are constantly occurring, and, if the scope of these processes is sufficiently great to change "the face of the earth," they are called *biospheric*. It is possible to provide a sufficiently clear classification of biospheric processes by dividing them into two categories:

—*those connected with the evolution of life*, as a continuous series of successively more complex forms, which in the final analysis has led to the formation of man as a biological species

—*those connected with the evolution of man* as a social being leading an intelligent way of life, i.e., the social evolution of man.

If this classification proves acceptable, then the biosphere from the standpoint of a systems approach should be defined *not simply as the place where interdependent processes connected with the evolution of life are realized*, but more precisely as *the system of connections within a space of the planet between the evolution of nonintelligent and intelligent life*, i.e., between the natural and human populations which coexist in geological time. These connections may be very diverse in their essence — from resource and trophic to moral and aesthetic.

To the biospheric processes connected with man's existence may be ascribed:

—the production of food based on livestock breeding and agriculture,

—the production of energy — hydroelectric stations, atomic and thermal power stations,

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*Antoine de Saint-Exupery, *Le Petit Prince* (Russian translation by N. Tal'), Moscow, Izdatel'stvo Tsk VLKSM Molodaya gvardiya, 1963.

—the production of housing (the construction of cities, or the so-called process of urbanization),

—the production of material wealth which facilitates the daily life of man, as a result of the development of light and heavy industry,

—the production of culture — the creation of spiritual values.

In the opinion of V. I. Vernadskiy [1] man's activity on the planet should lead to the conversion of the biosphere into a noosphere, of the sphere of activity of the human intellect. However, even given very great optimism — a feeling inherent to the physically and morally healthy man — we cannot today combine the evaluation of the state of the biosphere with the definition of a noosphere as "the triumph of the human intellect." Rather, more cautious and therefore more correct is the definition of the biosphere as the sphere of action of the processes of the production of food, energy, housing and culture, which are aimed at the creation of the conditions for the material and spiritual evolution of man, i.e., a technosphere. The existing loss of the metaphor in the definition of a "noosphere" is undoubtedly connected with one important circumstance — all the listed biospheric processes entail not only the production of a target net product, but also the production of a certain amount of associated products called "production wastes." In this, the elimination or reduction of "production wastes" would significantly increase the cost of the process of manufacturing an individual net product and, consequently, would raise its net price. At present no country is in a position to unilaterally agree to an increase in the net price of products, which would lead to a catastrophic decrease in the country's national income. Therefore, the problem of organizing "nonwaste-producing" production remains today an idea fashionable in intent and good in essence, which does not have a sufficient material basis.

On the contrary, the cheapening of the production of the net product inevitably exacerbates the problem of "production wastes." And when the nonspecific process of accumulation of "wastes," which accompanies directed production, reached biospheric scopes, human society began to worry, forcing national governments to put to scientists the question: what are the possible consequences for man and the biosphere of the accumulation of "production wastes"? "Bad!" the scientists of different continents answered unanimously. But since we have not succeeded in fundamentally changing the state of affairs with the production of wastes, inasmuch as the impelling reasons for decreasing the net price of output have not been eliminated, and it is all the same necessary to do something for the future of our children and grandchildren, the scientists were faced with a less clear cut problem, which may be formulated precisely enough in everyday language as follows:

"Well, fine . . . since there are, and will be wastes, nothing can be done. . . . But tell me then, how much waste can enter the biosphere without this, in the final analysis, having an effect on our health and the future of our children?"

The question is correctly posed and at the proper time. And even when we, scientists, give it an intelligible answer, it is still not at all evident that human society will draw the correct conclusions from it or, more precisely, will find in itself the strength to follow the advice, which is based on precise knowledge of things and the state of affairs.

"PRODUCTION WASTES" AS ANTIREPRESSORS OF BIOSPHERIC PROCESSES

Any process, regardless of its physical nature, can be described by the parameters "input," "processing speed" and "output." With respect to biospheric processes, the conditions of the "input" are determined by the concentration of basic components (C) — in the form of the basic raw material and its diversity, as well as their reactivity (K) — with consideration for their accessibility and with consideration of the time and difficulty of delivery to the point of production. The "processing speed" depends not only on C and K, but also on the organization of production with consideration for possible change (usually growth) in its scope. Finally, the conditions of the "output" are determined by the amount of the net product (P) and its quality (Q), as well as by the production of a certain amount of wastes (O), which reduce the net price p. With respect to biosystems, of primary significance is the "quality" of the wastes, in the sense that when the quality of wastes is better, the lower their toxic properties.

Let us note that the net product under the conditions of intensive production (more precisely, overproduction) may act as a repressor of the process, or repression will be slowed as a result of reducing the net price of the product owing to a change in the ratio of P and O in favor of the latter. Thus, "production wastes" at a specific stage of development of society act as antirepressors of biospheric processes, decreasing the net price of the net product. This should indicate that the exacerbation of the problem of wastes also has the value of a warning, since it precedes repression of the processes of production of the net product.

This short digression into reality should illustrate the obvious situation, that the problem of future evolution of the biosphere in essence has already ceased to be a purely ecological problem. In it the economic, social, ecological, and other aspects are woven into one whole, into one system, making the problem biospheric. Hereafter we will not examine the general outlines of the entire biospheric system — at the center of attention will be, above all, ecological problems and the problem of the permissible influence of wastes on biosystems. However, some general principles going beyond the framework of ecology will nevertheless be formulated as concepts, which make it possible to better elucidate the features of the biospheric model.

MODEL OF THE BIOSPHERE

Figure 1 schematically depicts the biospheric model. The features of the model are:

- —The model envisages the consumption of the energy of the sun and the resources of the biosphere — the former is negligible, the latter is approaching the level which will limit the scope of biospheric processes.
- —The model concerns the historical aspect of the development of the biosphere, as a developing, self-organizing system striving for equilibrium.

The biospheric model has many features in common with the model of ecological succession:

- —*The prevalent importance of "input" at the early stages of development of the biosphere,* when the system develops *"as if"* there are unlimited resources in an unlimited space, i.e., under the conditions of exponential growth. Such a system is essentially nonequilibrious and upon rough approximation may be regarded as an open exposed system, see Figure 1A. Natural ecosystems can easily handle a small amount of wastes, mostly household wastes, without appreciable disturbances in the biosphere.
- —*The "equal importance" of input and output in a balanced equilibrious system,* when factors limiting development come into force. Exponential growth in this case is replaced by growth dependent upon the repressing (the increasing role of the products of output as repressors of biospheric processes), limiting (the exhaustion of irreplaceable resources) and injurious (the harmful effect of wastes) mechanisms of the system. Feedback, which envisages a slowing of reaction, makes it possible upon a rough approximation to regard the sequence of the processes being realized in the biosphere as a closed loop of transformations in an essentially equilibrious isolated system (Figure 1B). In order that such a system might stably exist for a long period of time, there should be envisaged the possibility of replenishing the source of resources (most reasonably, through the connection of S and R), as well as of the appearance of regulatory connections between P and O, E-I and E-II, as well as P and E-II (Figure 1C).

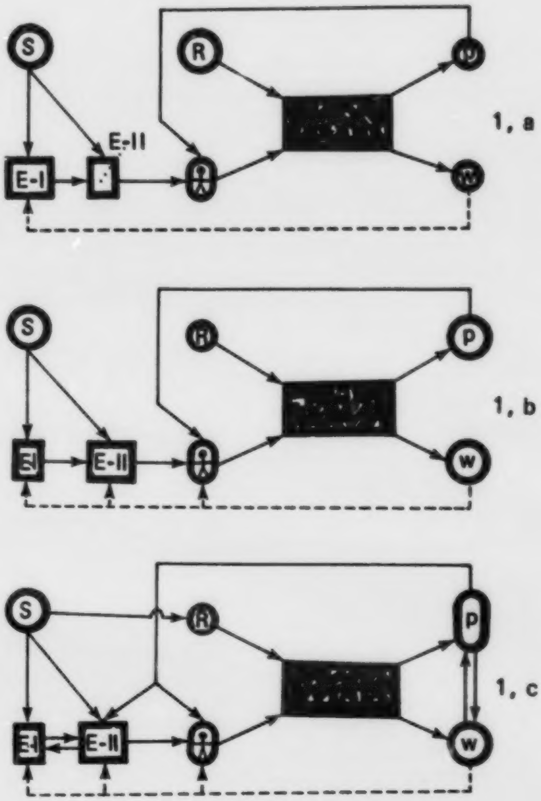

Figure 1. Schematic of biospheric model.

Both stages of the "biospheric succession" reflect only the most vivid features of the states of the developing system, when there passes through the system a flow of energy that substantially changes the entropy of the components forming it [2]. Finally, it would be interesting and might be even important to establish the location of the biosphere of 1975 on the path of its conversion into an equilibrious system. Of course, we are still far from a solution to the questions of replenishing resources through solar energy, and enormous organizational difficulties are preventing the establishment of connections between P and O, E-I and E-II. However, we can state that tendencies to "close" the processes in the biosphere are at hand. Indeed, local crises of overproduction of individual types of net products, the problem of the negative effect of wastes on man and natural ecosystems irrefutably attest that the general contours of a closed system are appearing very distinctly. True, the currents of transformation in such a system are still not balanced, and one might believe that the appearance of a closed loop of transformations makes it possible to define the present state of the biosphere as intermediate between the two extreme, above-described, states.

The biosphereic model makes it possible to determine the sphere of questions belonging to the competence of ecologists and, in particular, the participants of this conference. The central issue is the question of the maximum permissible loads of "wastes" (in the broad sense of this term), which can be borne by man as well as by natural and artificial ecosystems, without the risk of *collapse* of the basic biological structures determining the appearance of biosystems. It is important to emphasize that at issue, are irreversible and unbalanceable changes of biosystems, as a result of which, either the biosystem collapses and ceases to be a system, or its structural changes are so substantial and stable that we have the right to speak of the "rebirth" of the old system into a new one, with its inherent new totality of values that determine its new appearance. Here, it is easy to see that the possibility of "rebirth" pertains exclusively to ecological systems, while the irreversible degradation of systems, which is caused by the effect of wastes, concerns all biosystems without exception, including the human organism. Thus, the potentially dangerous effect of wastes threatens above all the health of man. This influence may be direct, if the "wastes" directly cause different functional disturbances in the human organism, being the cause of illnesses. The study of this type of influence of wastes goes beyond general ecological research and belongs to the competence of public health services. The effect of wastes may be caused by their entrance into an organism along with food of plant and animal origin. In this case, the field of activity remains outside ecology, since the pollutants pass from the environment into ecosystems being utilized by man, accumulate in the bodies of organisms, migrating along the trophic chain all the way to the finished product in the form of a biomass of organisms used by man for food. The latter act not simply as passive carriers of pollutants from the environment to man. By accumulating and transforming pollutants, animal and plant organisms, in turn, experience the effect of pollutants, which in the final analysis influences the dynamics of the sizes of populations of natural ecosystems, i.e., changes their structure. In this case, of especially great importance is, within the ecosystems utilized by man, the separation of the species on which "man is supported" (i.e., uses for food), from the other species which coexist with the former. Here, strictly practical considerations stimulate the interest of ecologists not in studying the structure of communities in general, but in studying the fate of individual populations that are valuable for food. Thus, the paths of the effect of wastes, which "lead" to man, in essence are ecosystemic, and we should substantiate some new concepts of the approach in the study of the biospheric model, and of its "ecological unit."

TWO USEFUL CONCEPTS IN THE STUDY OF BIOSYSTEMS

The *first* concept — the concept of "alternative mechanisms" — is based on the postulate which can be formulated in the following way: *any final formation in biosystems is capable of emerging in more than one way.* This tenet implies the existence in a living thing of alternative mechanisms of formations (emergences). The concept "formation" sounds somewhat abstract and should be made specific with respect to different types of systems in a different way. Thus, for a-type biological systems [3], a "formation" should be considered any intermediate or final product of the processes (substance, compound) which participates in forming the structural components of the "biological spectrum" — gene, cell, organ, etc. Indeed, of the several hundred induced biochemical reactions in an organism, it is hardly possible to name an example of the sequence of "conversions" of intermediate products, which result in a synthesis of any component, a sequence that would not be duplicated by another sequence, with the component synthesizing the same component. For r-type biological systems, we can regard as the final formation the climactic state of a community that is in equilibrium with a complex of factors, which determines the living conditions of each specific biotope. Here the "serial stages" on the path to the climax can differ substantially for the biotope of one type. With respect to the biospheric model it is also possible to postulate the existence of alternative means which regulate the rate of the processes of interaction between the elements of the system.

As is evident from Figure 1, the wastes from biospheric processes are capable of having a negative effect (dotted lines) directly on man's health through the food chain, entering man's organism along with food (I); on the productivity of exploited natural ecosystems, i.e., a reduction in man's food base (II); as well as on the fate of natural ecosystems which are little or not at all exploited by man, i.e., on biospheric processes connected with the evolution of nonintelligent life on the planet (III).

Figure 2 depicts in conformity with the concepts of alternative mechanisms the elementary unit of the interacting elements of the system.

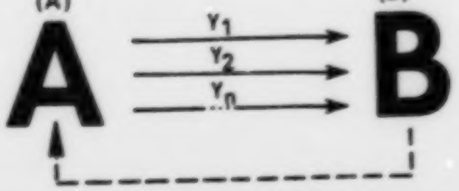

Figure 2. Individual units of the interacting elements.

From the laws of chemical kinetics, it follows that the observable rate of the process of formation, which depends on the concepts of the initial product (A) and the product being formed (B), in reality will be some additive resultant magnitude $\bar{v} = v_1 + v_2 + \ldots + v_n$. Therefore in some domain of the values, given $\bar{v} = f\,(A,B) = \text{const.}$, the change in v_1 will be offset by a change in v_2, and vice versa. The existence of alternative mechanisms which maintain the constancy of the characteristics of the final output of the process make it possible to apply to the work of the individual unit of the interacting elements (Figure 2) the generalized concept of homeostasis [4]. If we accept that the concept of homeostasis extends to the mechanisms of maintenance of the constancy of some characteristics ($\bar{v}$) owing to the inconstancy of others (v_1 and v_2), then the homeostasis of the system is "a mechanism of regulation, which orders in time a change of the features of the system in the direction of the stability of the group of characteristics pertaining either to the processes (r-system—for example, all ecological systems), or to their results (a-system—for example, the organism of man)" [3].

The *second* concept — *the concept of the "statistical norm"* — is based on the postulate which is formulated in the following manner: *the totality of values characterizing the "output" of the processes regulated in the system by homeostatic mechanisms, in the norm are subject to Gaussian distribution.* This tenet implies the possibility of control over the processes being realized in individual sectors of the biospheric model. With the aid of the criterion of correspondence (χ^2) or approximate methods of verification, which are connected with the calculation of the index of asymmetry $g_a = M_3/s^3$ and excess $E = M_4/s^4 - 3$, where M_3 and M_4 are the empirical central moments, and s is the standard deviation, one is easily convinced of or has doubts about the adoption of the hypothesis of normality. If the magnitudes of g_a and E are small and the hypothesis "passes," it can be assumed that the totality of values characterizes the state of the "norm." Then the negative influence of the existing level of "wastes" can be considered offset by other processes of the system and, consequently, within the framework of the maximum permissible effect. On the other hand, if the hypothesis of normality "does not pass," then the magnitudes of the values $g_a > 0$ and $E > 0$ may be regarded as indices of the deviation from the norm, i.e., be a measure of "pathology." Such sectors in the system require man's operational interference, since they should be considered to be outside the limits of the permissible effect of wastes.

Finally, for the case when the factors distorting the result of the measurement cause an effect proportional to the very result of the measurement for example, in the case of a *sudden* one: (a) of a massed effect according to the "old" connection of the contour — the so-called "emergency overloading of the connection," (b) the emergence of a "new" connection in the contour — for example, a direct negative influence of a "waste" on some biospheric process, the totality of values is usually subject to the log-normal distribution, when not the results themselves of the measurement, but their logarithms follow the Gaussian distribution. In this case it is not the absolute, but the relative errors of measurement that are stable on the average, and, as an evaluation of the average value, the most representative is not the mean arithmetical (v_a), but the mean geometrical value (v_g). Then a convenient index of the "deviation from the norm" might be the ratio of the mean arithmetical value to the mean geometrical value, i.e. [5],

$$v_a / v_g = \frac{\frac{1}{n} \sum_{i=1}^{n} x_i}{\sqrt[n]{\overset{n}{\underset{i=1}{\pi}} \cdot x_i}}$$

Both concepts — alternative mechanisms and statistical norm — are especially suitable for the case of the equilibrious model of the biosphere, see Figure 1B, when the currents of substances are balances, which increases the homeostasis of the system as a whole. This makes it possible to introduce into the evaluation of the state of the biosphere, certain integral system characteristics such as reliability, stability and others, for whose analysis there are developed approaches and appropriate mathematical apparatuses. However, for the "intermediate" state of the biosphere of 1975, see Figure 1B, the above-formulated concepts are more useful, not so much when studying the biospheric model as a whole, as when analyzing its individual parts, which pertain to the processes regulated by homeostatic mechanisms. Among the nodal sectors we should place the natural ecosystems that are exploited and unexploited by man (E-I and E-II). Here the central problem, whose resolution rests on the shoulders of ecologists, is connected with the task of examining the force of resistance which can be exerted by ecosystems (owing to the homeostatic mechanisms) against the effect of wastes with consideration for the toxicity of the latter (the problem of the "ecological" quality of wastes). The ability of ecosystems to resist the effect of wastes has the goal of establishing the maximum permissible level of their introduction into the ecosystem, i.e., the level at which the main indicators characterizing the state of the ecosystems (above all their productivity and stability) remain within the limits of the norm. In the final analysis the solution of this basic strategic task of applied ecology is inevitably reflected in the truly scientific determination of the permissible scale of "production" of wastes in the biosphere, i.e., the formulation of ecological conditions of the maintenance of the equilibrium of the biosphere.

THE STRATEGIC AND TACTICAL TASKS OF APPLIED ECOLOGY WITHIN THE FRAMEWORK OF THE BIOSPHERIC MODEL

In formulating the strategic task it can be said that within the framework of the biospheric model it reduces to the need to study the consequences for the biosphere as a whole of the changes caused by wastes in its ecological unit (E-I and E-II). In spite of the obvious simplicity of the formulation, the solution of this task apart from a purely practical interest also has a philosophical aspect, concerning the problem of "the whole" and "the parts." There are two alternative views of the features of the interrelation of "the whole" and "the parts."

The *first* asserts that the *whole* does not represent anything that is not in the parts. The *second* asserts that the whole is nothing more than the sum of the parts. The systems approach, which is so popular and constructive in science today, unequivocally speaks in favor of the latter point of view, placing an equal sign between the concepts "the whole" and "the system." Indeed, if we regard a system as a totality of the orderly interacting and interdependent components (elements), then it is easy to realize that it is precisely the *connections* between them that give rise to new features, and these "new" features are formed into new characteristics inherent to the system as a whole, and then the entirety of the interacting elements (parts) forms a single whole, i.e., a system. Therefore:

—The study of the connections in the system in a definite sense is more interesting and promising for comprehending the whole than the study of the features of the elements (parts) forming the system.

—The analysis of the system, which is preceded by a breakdown of the connections between the elements (i.e., the breakdown of the whole into its parts), does not make it possible to effectively study the integral feature of the system and, consequently, modeling — as a methodological device — is a most important device for studying systems.

—With respect to ecological systems, a third consequence could be formulated, which follows from the postulate "the whole = the system." Any biological study belongs to ecology only insofar *as it helps to understand the phenomenon being studied* in the ecosystem. Study undertaken in another connection — of the same feature of living beings or of the same biological phenomenon — ceases to be ecological and pertains in each individual case to other appropriate sections of the biological sciences.

In particular, the latter consequence clearly outlines the sphere of phenomena pertaining to the department of ecology as the science of ecosystems or, more precisely, the science of the systems of the superorganism level of organization, within whose limits the society of organisms and the environment function together as a single whole.

It is interesting that the basic tactical task of applied ecology so to speak "in the ecological context" also concerns questions of the interrelationship of "the whole and the parts," and can be formulated by analogy with the strategic task as

—The need to study the consequences for *the ecosystem* as a whole *of the changes caused by wastes in its individual sections.*

In other words, the task reduces to the determination of the "tenacity" of ecosystems as a whole, given local damages — of individual functions within the entire society being examined or the complete "mortification" of a part of the society within some space. Diverse wastes are the damaging factors. They function as a measure of the "tenacity" of ecosystems, as the diverse indicators of stability, which pertain to the ecosystem as a whole or to its parts.

The tactical task of applied ecology can be easily formulated, which facilitates the subsequent analysis of the situation and development of regulatory and preventive measures for protection of ecosystems from harm. Let the state of the ecosystem be defined by the total combination of values pertaining to the processes with homeostatic mechanisms of regulation. "In the norm," the magnitude of the values are subject to Gaussian distribution and, as dependent variables — $Y_1, Y_2, \ldots, Y_m$ — they characterize some set function from the arguments $X_1, X_2, \ldots, X_n$, which are independent variables. The latter characterize the total combination of disturbance characteristics for specific types of pollution. Thus, the task reduces to finding the equations of $X_1, X_2, \ldots, X_n$, for which the values of $Y_1, Y_2, \ldots, Y_m$ remain distributed normally, see Figure 3.

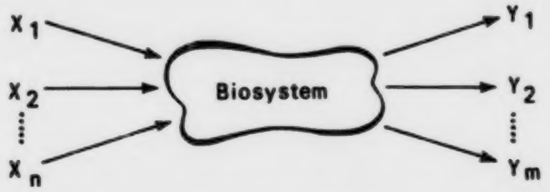

Figure 3. Specific characteristics pertaining to individual disturbance sources (x_n) and individual responses (y_m) in the system.

Useful in this case is the study of dependencies of the type:

- —$y_m = f(x_n)$, where y_m and x_n are specific characteristics pertaining to individual disturbance sources and individual responses in the system respectively;
- —$a_n = f(\Delta x_n)$, where a_n is the index of the asymmetry of the values of the function, and Δx_n is the change in the level of the disturbance factor;
- —$a_n = f(A_n)$, where A_n is the index of the asymmetry of the disturbance factor, if a priori it is known or can, with a sufficient degree of reliability, be assumed that "in the norm" the disturbed factor is also distributed normally.

When resolving the formalized task in general form we should pay attention to the features of the study of dependent and independent variables in ecosystems.

FEATURES OF THE EFFECT OF THE DISTURBANCE FACTOR

We can single out two extreme cases pertaining to the features of the effect of disturbance factors of the environment on ecosystems.

The *first* pertains to an increase in the background level of individual types of the application (the section) of the disturbance source in the biospheric model, and even in that part of it which pertains to ecological systems. The increase in the overall background of individual types of production wastes within the connections foreseen by the model makes ecologists quite helpless in the matter of predicting the expected consequences in the fate of ecosystems. For example, the discovered tendency for a rapid increase in CO_2 in the atmosphere of our planet is capable of resulting in the most unforeseen and, perhaps, unpleasant consequences. The latter are so diverse in their nature and direction, that to make a reliable prediction does not seem possible.

Only within model experiments is the ecologist capable of studying individual details as, for example, will the increase in CO_2 concentration intensify the process of photosynthesis? Another useful method might be the creation of so-called "preliminary" models, i.e., extremely simplified copies of the real world, which make it possible to find the "nodal points" in the control of the behavior of systems.

If given the background effect we succeed in finding gradients for the individual disturbance factors, then the possibility arises of making, in accordance with the gradient, a biological analysis of the changes in the structure of ecosystems through the selected indices — $Y_1, Y_2, \ldots, Y_m$. The main emphasis here should be made on the change in the relative abundance of populations and, of course, on the change in the species composition of the ecosystem, which is connected with the disappearance of individual species. With this approach the finding of the correlations between the level of the disturbance factor x_i and the change in the biological indicators y_j is the main method of finding the connection between the dose of the influence and the observable response (dose-effect).

The *second case* concerns the local damage to connections or sectors in ecosystems by specific types of wastes. Usually the magnitude of the emission is clearly insufficient to cause background changes within a large ecosystem (biome) or even a biosphere. Mercury and its compounds, which are used as a fungicide in disinfection of seeds and are later discharged into bodies of water with waste water, may serve as an example of such a pollutant. The mercury compound is transformed in the environment into highly toxic methyl mercury, which accumulates in living organisms and, entering man's food together with a product (usually fish) can serve as a source of poisoning of the population.

It is methodologically simpler to study the effect of local pollutants than that of background pollutants, since the organization of the experiment affords effective opportunities for the study of the connection of x_i with the diverse responses of the system — $Y_1, Y_2, \ldots, Y_m$.

During this study in the experiment of the selected indicators of the state (i.e., Y_m), one should consider the *simultaneous* effect on ecosystems of many disturbance variables, some of which may pertain to background, some to local and, finally, some to attendant factors of the environment (changes not caused by the negative influence of disturbances such as the seasonal changes in light and temperature).

For predicting the "fates" of the behavior of ecosystems it is absolutely necessary to consider and quantitatively evaluate the interaction of the disturbance sources frequently even of a different physical nature. Thus, the strategic base of the study of ecosystems, in which the effect X_n and the response Y_m should be connected by a quantitative dependence, can be formed by a multifactor experiment, which is planned on the basis of economical and mathematically substantiated patterns of experience. The latter envisages the possibility of studying the simultaneous and independent influence of a large set of variables on biological systems of a different degree of complexity [6]. Such an experiment has the goal of studying the probable, expected situation which may be forecast on the basis of the tendencies of changes in the environment, which are found when registering the changes in time and space of the individual disturbance factors of the environment [7]. As a result of the arrangement of the experiment there can easily be obtained polynomial models of the description, which contain quantitative evaluations of the effect of the variables [8]. These evaluations in the future may be useful for obtaining approximate evaluations of the coefficients in differential equations when constructing dynamic models.

CRITERIA OF THE BIOLOGICAL RESPONSE

In the preceding section, when discussing the features of disturbance factors, it seemed to be implied that ecologists are capable of differentiating quite simply:

On the one hand, the response Y_1, which is caused by a pollutant (the harmful source, indicated in Figure 1A by the line of dashes), from any other changes in the ecosystem, which are not connected with pollution (for example, seasonal changes, successions); and, on the other hand, are able to differentiate a response-caused pollution and leading to irreversible changes in the system (collapse or rebirth into a new ecosystem) from a response caused by the effect of a pollutant, with which the system is capable in the end of dealing. In this case we are in a position to study the question: what reserve of durability does an ecosystem have in respect to the *harmful* effect of disturbance factors? An answer may be obtained if the indicators selected for study and control (i.e., the dependent variables) are sufficiently representative for a determination of the state of the ecosystem. Unfortunately, the establishment of the priority of responses in a series presents many difficulties. Thus, it is possible to state that if the number of independent variables, whose effect is studied in the experiment, can be sufficiently large, but unquestionably limited, then the number of registered responses in the series $Y_1, Y_2, \ldots, Y_m$ presents many difficulties. Thus, if the number of independent variables, whose effect is studied in the experiment, can be sufficiently large, but unquestionably limited, then the number of registered responses in biological systems can be practically endless, since any feature of a living thing can serve as the object of control. Therefore, when selecting from the infinite series Y_m a limited number of indicators, one should rely on some specific principle of selection, i.e., a necessary discriminating criterion.

Let us examine two approaches and their appropriate criteria.

The *first approach* is the professional-specialized approach, when specialists in a narrow field (for example, botanists, biophysicists, hydrobiologists) have specialized knowledge that encompasses all existing aspects or features of the object of study. Corresponding to this approach is the *intuitive criterion* of discrimination in ranking according to the importance of the features being studied. This criterion reflects in vague form the accumulated (at times even unrecognized) experience of the specialist in resolving what is more and what is less important in the normal object of study. As an example we can cite the point of view of a hydrobiologist who makes an a priori ranking of dependent variables. Thus, when regulating water ecosystems there is, above all, suggested the idea of using as a response the most ordinary and traditional indicators of hydrobiology: growth (productivity), expenditure (respiration, life-long rejection of organic material), state (consumption and assimilation of food, rate of accumulation in hydrobiotas of individual pollutants) and others. It is completely evident that the creation of regulatory systems based on traditional indicators is in principle of little effect, since any biologist specializing in a narrow field is capable of developing a substantiated scheme of control over "his own" object. Such studies are intended for long periods of time by specialists with a high level of training and, having entered on this path we would in essence have to admit to the need for reforming (reorienting) in the direction of solutions of the tactical task of applied ecology of all the biological sciences and disciplines cooperating with ecology.

The *second approach* can be called the systems approach. It is this approach that determines the content of modern ecology. The concept of levels should unquestionably be recognized as the main concept of the systems approach. To solve the tactical task of applied ecology it is useful to slightly expand the "ecological spectrum" of levels of organization, which is limited by populations and communities. Thus, for the needs of regulation it is useful to single out the following five levels of biological organization:

—subcellular — Y_I
—cellular (organism) — Y_{II}
—population — Y_{III}
—trophic grouping (associative) — Y_{IV} (simple community)—Y_{IV}
—community—Y_V—(complex community).

The first two levels are outside the sphere of ecological study, yet the information about subcellular and organism disturbances, evidently, can be useful not so much for evaluating the state of ecosystem according to the selected Y_i, as for establishing the "harmfulness" of the factor disturbing the system, since the information from Y_I and Y_{II} is often necessary for obtaining evaluations characterizing the environmental quality, i.e., the "toxicity" of individual independent variables.

It is easy to see, however, that the introduction of the concept of levels of organization is capable of somewhat narrowing the spectrum of biological levels, owing to the discrimination of a series of levels — gene, tissue, organ and others. However, within each level the number of possible indicators is excessively great. In order to significantly reduce the number of selected variables, we should use in addition the above-formulated concepts of "alternative mechanisms" and "statistical norm," which make it possible to introduce the discriminating criterion of the selection of dependent variables. In fact, being based on the concept of hypostasis, this criterion may be called *conceptual*. By using the conceptual criterion it is possible to formulate the following requirements of discrimination, which are made on the dependent variables within each level of organization.

The *first requirement* — to control the state of biosystems one should select indicators which pertain only (!) to processes with homeostatic mechanisms of regulation.

The *second requirement* — given that the first requirement is observed, preference would be given to the Y_i that characterize the *nonspecific response* with respect to various factors that disturb the biosystems (for example, elevation of the body temperature of an animal with various "diseases" of the organism, or a decrease in species diversity within a trophic grouping under the influence of pollutants that are diverse in their nature).

The *third requirement* — given that the first two are observed, preference should be given to the integral indicators Y_i and first of all to those which can be quickly and reliably measured by instruments. Thus, an example of such integral indicators in a living biomass would be the content of ATP (adenosine triphosphate) and chlorophyll, which characterize respectively the amount of living material and the amount of energy going into the system.

It should be noted that work on the selection of indicators is being actively conducted in laboratories of the department of hydrobiology of Moscow State University. Preliminarily it can be reported that a suitable indicator that satisfied the above-formulated requirements for levels I-V could be:

—for Y_I—the membrane potential of cells, which can be measured with microelectrode equipment,
—for Y_{II}—an increase in intensity of respiration,
—for Y_{III}—the evaluation among individuals of the population of the bilateral symmetry in the distribution of features, the time of generation, the ratio of sexes, the ratio of age groups,
—for Y_{IV}—species diversity, chlorophyll content,
—for Y_V—ATP content, ratio of the products of different trophic groupings.

The listed indicators should be regarded as illustrative examples. The selection of indicators substantiated by the conceptual criterion is continuing, and their priority is being discussed. But even now it is becoming evident that their number can be substantially limited. Thus, the formulated concepts and requirements make it possible to transfer the subsequent discussion to the question: in what way is it possible to interpret the evaluation of the ranked series of indicators, Y_i, with respect to the evaluation of the state of the entire ecosystem?

HORIZONS OF APPLIED ECOLOGY

Vladimir Vladimirovich Mayakovskiy had one childhood, well-known poem, "What Is Good, What Is Bad."

The poet dealt with the problem, using specific examples of bad and good human deeds. It is easy to follow the parallels between the poet's solution of the problem and the position of ecologists. Ecologists can also cite examples of what is "bad" for the ecosystem — both from observable tendencies of the change in indicators (for example, a decrease in productivity or diversity) and from the features of the dispersion of the evaluations of the selected indicators, Y_i, which "in the norm" should be distributed normally. This means that the ecosystem as a whole is "healthy," or at least is successfully resisting the negative effect of disturbance factors. In this case it is possible to consider it stable, and therefore all the values of the evaluations of stability, derived by "any means," outline the domain of the values of the "norm" of the ecosystem. This, if you please, is a type of "ecological zero," the source of reference of the health of the ecosystem. Much more likely is the situation when a part of the indicators Y_i within levels I-V, attest to a "pathology," while the remainder of the indicators attest to the "norm."

What is to be done in this case? What judgment does the ecologist have the right to pronounce?

Today this question is entirely unelaborated, and we have the right to consider it as one of the most difficult, most vital and most important for the solution of the tactical task of applied ecology.

"Pathology" of some indicators and the "norm" of others place before the ecologist a strictly medical task, which is resolved by the therapist — this is the task of "diagnosing" the disease. It can be postulated that definite regular combinations of "norms" and "pathologies" of individual indicators are specific for different types of "diseases" of ecosystems, or even are specific with respect to the different physical nature of the disturbance factors or pollutants (i.e., to the specific nature of "wastes" in the broad sense of this word). Then the set of features in the responses Y_i for all levels I-V, under the influence of one pollutant (for example, organotin compounds) will differ significantly from the features of the "behavior" of the responses, under the influence of another pollutant (for example, chlorinated phenols). If this is correct—and in my opinion it should be correct—then a list of the symptoms of each disease can be compiled. And then the establishment of a diagnosis of a disease is equivalent to the establishment of the nature of the "pathogen" of the disease, i.e., the nature of the disturbing influence. Therefore, the study by ecologists of the specific effect of specific wastes according to the selected indicators will make it possible to make a classification of diseases according to the type of changes occurring in ecosystems. In turn, the establishment of the origins of the negative influence of wastes on the ecological unit will make it possible to regulate the rates and scopes of the industrial, agricultural and domestic wastes being admitted into the biosphere.

If we succeed in making a "classification" of the disease of the ecosystems according to the selected indicators, then the next stage of the ecological study of ecosystems within the framework of solving the tasks of applied ecology would be the "clinical" study of the individual illnesses, i.e.,

—observation of the development of the disease, i.e., of the deterioration of the state of ecosystems, and

—observation of recuperation, i.e., improvement of their state.

Undoubtedly, this would require the organization of a broad range of experimental studies on different types of ecosystems, so that the "clinic" of the individual illnesses would be studied thoroughly and comprehensively.

This "medical" stage of the ecological studies is today still in an embryonic state, but given the present rate of development of science and, primarily, the interest of society in the problems of applied ecology, we can hope for its relatively speedy completion. For time does not wait, and mankind must reduce to a minimum, the inconveniences caused by the conversion of the biosphere from the "intermediate" stage of 1975 to an equilibrious state, when the technosphere of today will be transformed into a noosphere, the advent of which was heralded by V. I. Vernadskiy [1]. However, today the state of the biosphere and the position of man in it seem serious enough to cause the people on earth to be wary. Therefore, in ending this report I will permit myself once more to recall the delightful children's book, which was written for adults:

> "And here on the planet of the Little Prince there are terrible, vicious seeds. . . . These are the seeds of the baobabs. The soil of the planet is completely infested with them. And if the baobab is not recognized in time, you will never get rid of it. It will take over the entire planet. It penetrates it to the core with its roots. And if the planet is very small, and there are many baobabs, they will tear it to pieces" (ibid., p. 20).

Our planet — the planet of people — like the planet of the Little Prince, is also choked with "terrible, vicious seeds." But these are not baobab seeds, these are the "wastes" of economic processes. It is impossible to permit these seeds to sprout and tear the biopshere "into pieces," as it happened with one planet, on which lived a lazy-bones. Once he did not weed out three little bushes in time . . . .

Although the people of the planet Earth are by no means lazy, I would like to end my presentation with the words of Antoine de Saint-Exupery (ibid., p. 22):

> "I can bear to preach to people. Yet few know the threat of the baobabs . . . . that is why this time I have made up my mind to betray my self-control.
>
> " 'Children.' I say, 'Beware of the baobabs.' "

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ON THE ECOSYSTEM'S STABILITY

A. M. MOLCHANOV

INTRODUCTION

This report contains an attempt at the theoretical analysis of the types of influence of man on the environment.

Even the simplest mathematical model reveals at least four possibilities — the influence may be pulsed or long-term, it may be exerted on the system itself or affect the regulatory connections.

Therefore, the posing of the question about the maximum permissible loads depends both on the properties of the system and on the nature of the influence.

THE STATE AND THE PROCESS

The state of any system, including an ecological system, is given by the set of numbers characterizing the quantity or level of the components forming this system.

These important variables, which describe the system, are traditionally designated by x with various indexes. The number of variables is determined primarily by the complexity of the system, but depends as well on the desired extent of detailing. Thus, for example, the total number (or biomass) of trees on an area under study may be divided according to species, height, or age.

However, such data are sufficient only for the purposes of classification ("inventory taking"). For the tasks of prediction, and all the more so for the tasks of management, additions and refinements are needed.

The subsequent fate of the system in question essentially depends on the siuation in which it is found — the external environment. The state of the environment in turn is described by some set of numbers. We designate these numbers by the letter y with indexes.

At first glance it appears that we need to bring into the examination "the environment of the environment," to examine another series of letters, then the next one, and so forth, until all existing alphabets have been exhausted.

Strictly speaking, this is true. If, nevertheless, scientific study is at all possible, there must be a serious reason for this. This reason is that each system has its own characteristic time scale and these time scales usually differ radically for the system and the environment containing it.

The stated situation permits a simple and meaningful mathematical formalization:

$$\frac{dx_i}{dt} = f_i(x_1, \ldots, x_n; y_1, \ldots, y_e) \quad 1 \leqq i \leqq n$$

$$\frac{dy_k}{dt} = \varepsilon g_k(x_1, \ldots, x_n; y_1, \ldots, y_e) \quad 1 \leqq k \leqq e \tag{1}$$

The small parameter ε in this system is equal to the ratio of the characteristic time τ of the system in question to the substantially greater time T, which is necessary for appreciable changes in the properties of the environment:

$$\varepsilon = \frac{\tau}{T} << 1 \tag{2}$$

Thus, for example, the normal frequency of the pulse is one beat per second, and the periodicity of malaria attacks is one day.

Consequently, in this example

$$\varepsilon = \frac{1 \text{ sec}}{1 \text{ day}} = \frac{1}{24 \cdot 60 \cdot 60} \sim 1.1 \times 10^{-5} \tag{3}$$

A medical example and not an ecological one was selected in order to emphasize the common character of the notions being developed.

The structure of system (1) shows that the dynamics, the "life" of the variables x_i occurs against the background of the weak drift of slow evolution of the external parameters y_k. In many instances it is sufficient to set $\varepsilon = 0$.

The variables y_k then become constants:

$$y_k = \alpha_k \tag{4}$$

and enter as parameters the right side of the equations for dynamic variables

$$\frac{dx_i}{dt} = f_i(x_1, \ldots, x_n; \alpha_1, \ldots, \alpha_e). \tag{5}$$

Thus, for example, a sea shell might be found in the zone of alpine meadows at an altitude of 2500 meters above sea level. This internally contradictory statement signifies that we are not interested in the geological processes which resulted in the raising of the former ocean bottom to nearly 3 kilometers. We ignore the "geological epsilon."

FIXED REGIMES

The ignoring of the small parameter ε means consequently the fixing of external conditions. However, the state of the system in question may be completely different when given the same values of the external parameters $y = \alpha$.

A forest in a given area may be mature and healthy — this is one fixed state. The overeating of leaves by caterpillars will not kill the forest, but it will lead to another fixed state with sharply reduced photosynthesis. Finally, a fire, having consumed the forest, creates a third fixed state which subsequently will slowly evolve under fixed external conditions.

Mathematically this means that the equation for x may have several fixed states with the given parameters.

The basic ideas can be illustrated by the very simple example of one variable x and one parameter α;

$$\frac{dx}{dt} = f(x, \alpha) \qquad (6)$$

In this case the set of fixed states of the system which is given by the equation

$$0 = f(x, \alpha) \qquad (7)$$

is mapped by a curve on the plane (x, α).

The situation depicted above causes natural association with the universal biological notion of the states of activity and rest, which are characteristic of all biological systems. There is no doubt that such states are also characteristic for ecological systems. Moreover, the general mathematical approach is also fruitful in the analysis of social, technological and technical systems.

However, it is better to retain the biological, or, even, the strictly medical terminology, owing to the fact that the questions under scrutiny have been studied most of all in medical practice.

PULSED INFLUENCE

The states of activity and rest have a definite stability. The proposed model makes it possible to examine the basic types of reaction of a system to pulsed influences. It is natural to interpret such an influence as an instantaneous transfer from one point of the phase plane to another.

As was already said, visual biological representations on an organism level are the basis. The integration of the notions in the model makes it possible to construct their ecological analogue.

Let us examine the obvious possibility, when the state of rest is sleep, and the state of activity is awakeness. In this case the value x should be interpreted as the level of motor activity, while the parameter α should be tied with the level of excitation of the nervous system.

It is evident that this is an extremely simplified, illustrative description. Nevertheless, it is useful for an understanding of the possibility of a unified mathematical model that does not depend on the structural, morphological level of the system in question.

Thus, for example, it is possible to attempt to analogize the state of "activity" with the golden age of the Helladics, when the entire peninsula was covered with mighty oak forests. At that time the state of "rest" of this ecological system was its present dense condition of thorny bushes and outcrops of rocks. It is believed that the main cause was the goats which had not so much eaten up as they trampled down the underbrush. Freed mountain streams washed away the soil, and karst depressions completed the destruction. And now there are almost no goats and the streams do not rage....

Let us return, however, to the model (Figure 1) and examine the state of activity A, which is on the branch AA′. The pulsed influence on the system corresponds to the instantaneous displacement along the horizontal line which passes through point A. The nonlinear theory of oscillations suggests the name "phase impact" for such a change of state of the system. Such terminology is justified by the extensively widespread name "phase space" for the space of dynamic variables.

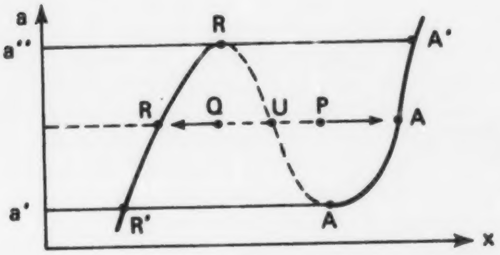

Figure 1. A system with a different number of fixed regimes. In the zone between α' and α'', there are three fixed regimes, whereas above and below this zone there is one for each.

Of course, the phase impact upsets the equilibrium, but if the disturbance has not thrown the representing point of the system beyond the line RA of the unstable states of equilibrium, then the system in agreement with the equation of motion (6) returns to the previous state of activity A. If the phase impact throws the system beyond the point U (on the branch RA), then the system enters a state of equilibrium at point R on the line of the states of rest.

Thus, the phase impact has a clearly defined threshold nature — to the right of U there is the full reestablishment of activity to the original level, to the left of U the system enters the state of rest.

It is necessary, of course, to bear in mind the arbitrary nature of the terminology — the state R should be considered "rest" only with respect to the state A. Thus, for example, a marmot may be awake or be asleep, or may become lethargic. The state of "lethargy" is "rest" with respect to activity, while sleep is rest with respect to lethargy. For our purposes it is sufficient to distinguish between two contiguous levels which differ with sufficient force in the intensity of the activity.

Let us now examine the consequences of the pulsed influence on the parameters of the system. The space of the parameters is called the structural space of the system, since to each point in this space there corresponds a completely defined nature of the dynamics of the system, its very own, as is said in the theory of oscillations, "phase portrait" of the system. Therefore, it is reasonable to call the pulsed influence on the parameters of the system a "structural shift."

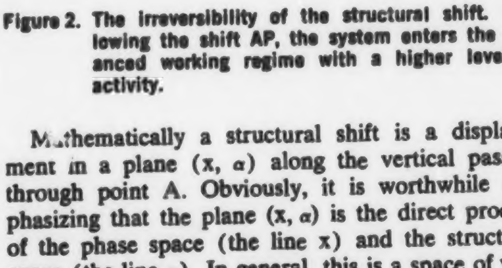

Figure 2. The irreversibility of the structural shift. Following the shift AP, the system enters the balanced working regime with a higher level of activity.

Mathematically a structural shift is a displacement in a plane (x, α) along the vertical passing through point A. Obviously, it is worthwhile emphasizing that the plane (x, α) is the direct product of the phase space (the line x) and the structural space (the line α). In general, this is a space of very great dimensionality, but the necessity of a clear depiction makes it necessary to limit ourselves to a very simple case. Besides, the basic concepts are sufficiently meaningful and rich even given this most simple case.

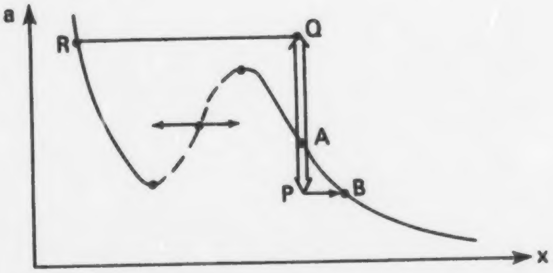

Figure 3. The gradual accumulation of structural reconstructions, which results in a breakdown into the inactive state R.

In contrast to the phase impact, the structural shift necessarily changes the state of the system — there is an "after effect."

The new regime that arises upon the achievement of equilibrium, which was disturbed by the structural shift, may be rest, may be a state of greater or less activity.

Another important property of structural shifts, which is closely connected with irreversibility, is the cumulative nature of such influences.

SLOW (EVOLUTIONARY) MOTION

Everything expounded above pertained only to rapid motions.

The next problem in difficulty is the calculation of slow changes of parameters. For lack of a better word we will call it the "evolution" of the system. However, it is necessary to bear in mind that this is not necessarily evolution in Darwin's sense.

The rapid motion of the variables x we would do well to call the kinetics, the dynamics of the system, while the slow internal structural changes of the parameters would be best characterized by the word "evolution," which opposes them verbally to the kinetics of the system. Thus, for example, the age changes of an ecosystem or organism are naturally called an evolution in respect to vital functions, metabolism and kinetics.

In order to emphasize that we are getting ready to examine an expanded system, let us return to the designation y for slow variables. They have ceased to be external parameters and have become equivalent. even though slow, yet all the same variables of the system.

Here is a simple example. In studying a forest, one might not be interested in the process of soil formation and might consider the soil qualities a given parameter. However, if it is a matter of hundreds and thousands of years, the standing timber takes an active and important part in the creation and change of the soil on which it grows. The reversion to y means, consequently, not only the expansion of the system, but also the significant increase in the time scale during which the study of the system takes place. Great time scales, let us say, geological ones, may no longer be included in such an examination. In conformity with this, the landscape features — river valleys, hills, watertight layers — also must be considered invariable parameters even for an expanded system.

Let us write out a more complete model:

$$\left.\begin{aligned} \frac{dx}{dt} &= f(x, y) \\ \frac{dy}{dt} &= \varepsilon g(x, y) \end{aligned}\right\} \qquad (8)$$

The points on the curve $f(x, y) = 0$ are no longer stationary points of our complete system.

Nevertheless, the motion in the vicinity of this line occurs considerably slower, with a velocity on the order of ε, and not one, as at the remaining points of the plane (x, y).

The points of the curve $f(x, y) = 0$ are called points of quasi-equilibrium, while those points which "attract" the rapid variables are called metastable. The points of true equilibrium, which correspond to the disappearance of both velocities (both rapid and slow motion)

$$\left.\begin{aligned} f(x, y) &= 0 \\ g(x, y) &= 0 \end{aligned}\right\} \qquad (9)$$

lie, of course, on the curve of quasi-equilibrium, and more precisely, at its intersection with the curve $g(x, y) = 0$.

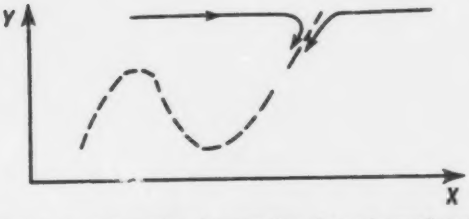

Figure 4. Rapid motion toward the line of quasi-equilibrium $f(x,y) = 0$, and slow evolution along it.

It stands to reason that this "true" equilibrium can be (and necessarily is) in turn a quasi-equilibrium in respect to even slower motions. We are assuming, of course, that the problem under discussion is correctly stated, for the necessary time scale, with consideration of all significant variables.

Thus, the existence of two time scales leads to two concepts of stability — metastability and complete (true) stability.

It should, perhaps, be noted that the hierarchy in the concept of stability is a reflection and consequence of a profound case — the hierarchy in the structure of the system being studied. Metastability and stability (for the sake of brevity we will not add each time the adjective "true") is the mathematical form of the important features of the structure of complex biological systems.

RAPID AND SLOW MOTIONS

The distribution of the points of equilibrium on the curve of equasi-equilibrium is of decisive significance to the properties of the system and the nature of its reaction to external interference.

Let us examine the case depicted in Figure 5, where the system has a stable equilibrium on the working branch AS, and on the branch of rest the unstable equilibrium U.

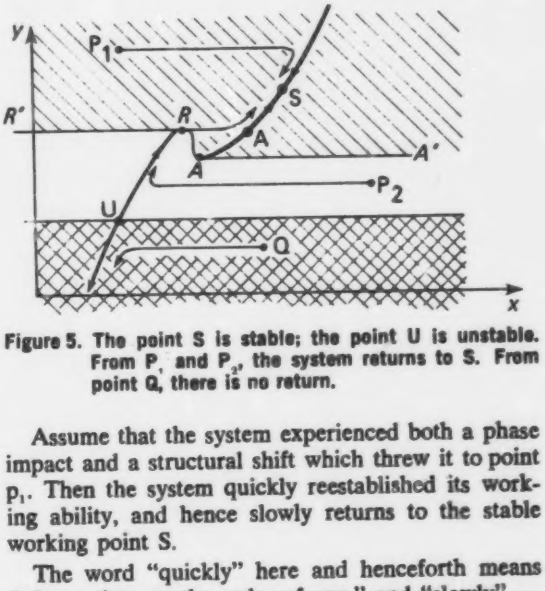

Figure 5. The point S is stable; the point U is unstable. From P_1 and P_2, the system returns to S. From point Q, there is no return.

Assume that the system experienced both a phase impact and a structural shift which threw it to point p_1. Then the system quickly reestablished its working ability, and hence slowly returns to the stable working point S.

The word "quickly" here and henceforth means "after a time on the order of one," and "slowly" — "after a time on the order of $1/\varepsilon$."

The system behaves differently when thrown to point p_2. At first it is even more active (x is greater than S), but this is "unhealthy excitation" and quickly "having expended its forces" the system falls on the branch of rest UR. Afterwards there occurs a slow "reestablishment of forces" — evolution to point R — then a return to a working state at point A. The evolution along the arc AS leads to the complete reestablishment of the original optimum state S.

The entire description is reminiscent of the history of a serious illness with a favorable outcome. For a more substantive understanding of the words "quickly" and "slowly" let us cite an ecological example. In the opinion of specialists, the already mentioned destruction of the forest in Greece occurred over two or three centuries, while for its natural reestablishment (evolution to point R) from ten to one hundred *thousand* years will be required.

Events develop even more dramatically when SQ is disturbed. From point Q the system quickly enters a "shock" state on the branch RU below point U and then there develops "progressive deterioration" — slow evolution draws the system further and further away from point S.

The entire plane (x, y) decomposes in the examined case into three domains.

The domain of stability lies above the line R′RAA′. Between the line R′RAA′ and the horizontal straight line passing through point U there is located *the domain of adaptation.*

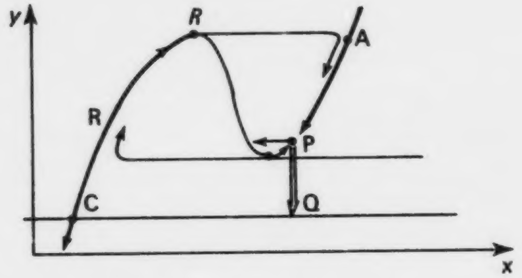

Figure 6. An adaptive system. The domain above the horizontal C is the domain of adaptiveness.

Below the horizontal of U is the domain of depression of the system, if by this we mean the inability to return independently to the state of original activity.

STABLE AND ADAPTIVE SYSTEMS

The existing biological systems have covered a long evolutionary (in Darwin's sense) path. Any of them have both stability and adaptiveness. But different systems have the properties in different proportions. This pertains especially to the ecological systems found under extreme conditions — tundra, desert, mountainous, saline. Unfortunately, this list has now been noticeably expanded by the irresponsibility of mankind.

It is thus more important to examine two extreme cases — adaptive systems with little stability and stable systems with little adaptiveness.

Let us begin with an example of an adaptive system.

The system loses its activity even with weak phase impacts, such as, for example, SU. It is even more sensitive to structural shifts. The shift SP already leads to a quick loss of activity and long recovery period R*R*. However, the system is capable of self-recovery and long-term activity in the sector of evolution AS. Moreover, even comparatively strong shocks such as the great structural shift PQ do not disrupt the system and even do not increase significantly the length of the recovery period.

Stable systems react differently to interference. Let us examine in detail the same function f(x, y), but with a different arrangement of the points S and C, which is determined, as we saw, by the properties of slow motion, i.e., of the function g(x, y).

The clearest feature of such systems is that they "do not know how to rest." They are able to quickly restore their activity even when there are strong phase impacts and structural shifts. However, the hitting of the branch of rest results in irreversible, progressive depression. For the system depicted in Figure 7, the domain of adaptation is the narrow zone ending with the arc RU.

As a venture it might be proposed that stability is characteristic of systems under favorable external conditions.

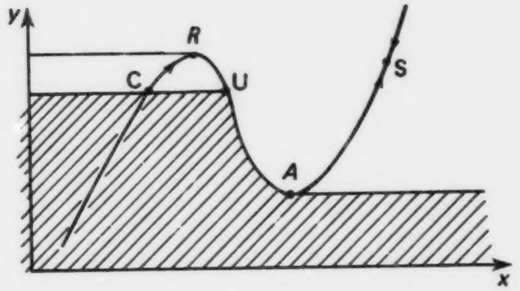

Figure 7. A stable system. The domain of depression begins immediately after the line CUA.

But if the conditions are unfavorable, the system should be adaptive so as not to be destroyed.

METHODOLOGICAL REMARK

From the viewpoint of quick, dynamic phase variables the two examined systems are identical.

The difference between them, and here a fundamental one, is found only with a careful analysis of the evolutionary equation (for slow variables).

Therefore, strictly quantitative approaches (such as, for example, imitation modeling, which was fashionable in the recent past) is suitable for watching after a system, for resolving current, tactical problems.

For the purpose of forecasting, the adoption of long-term solutions, and strategic planning the strictly quantitative methods are entirely insufficient and should be supplemented by a qualitative, systemic, structural analysis of the object in question, by a comprehensive study of the nature of its interaction with the environment and type of reaction to external interference.

HYSTERESIS

In practical work with any complex system — ecological, biological or technical — we usually have no opportunity to "look inside" the system. Therefore interference and direction occur, as a rule, "blindly" — by a change in the parameters of the system and the observation of its reaction.

From this point of view adaptive systems produce a strong impression on the researcher who is accustomed to stable systems. There the situation is simple — to each value of the governing parameter there corresponds a quite definite working regime.

But now the adaptive systems are "capricious." If we give some α today, the system works. If we give the same α tomorrow, the system does not react. And this is in the simplest case, when the system has in all two metastable states.

Meanwhile nothing prevents even a one-dimensional (but complex) system from having several regimes of a differing degree of activity.

In such systems there arise hysteretic phenomena that are described in the simplest case by the concept of the hysteresis loop.

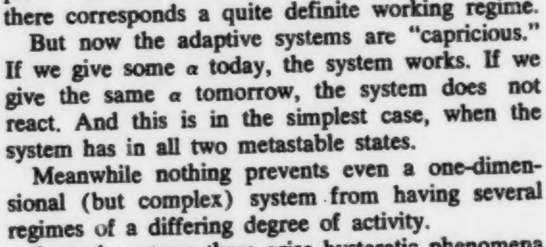

Figure 8. Four metastable regimes, which are divided by three unstable quasi-stationary states.

The phenomena develop in the following way. If the system is initially in state *R*, then the increase in the governing parameter α beyond the limit α'' leads to a breakdown in regime A. However, the attempt to return to regime *R* by a rapid decrease in α does not lead to the desired result — the system remains in regime A. There must be a very noticeable decrease in α — below the "lower threshold" of the hysteresis α' — in order to return to the branch of regimes R. In other words, it is possible to approach regime *R* only from below, and regime A only from above.

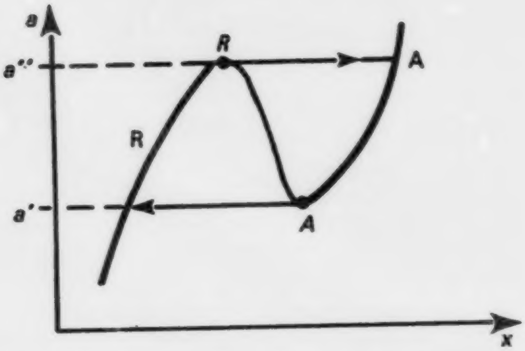

Figure 9. A hysteresis loop formed by the two branches of the regimes A and *R*.

RELAXATION AUTO-OSCILLATIONS

An additional remarkable situation is a distinctive feature of adaptive systems — they can exist in general without having a stable stationary state. This can easily be seen from the following celebrated example.

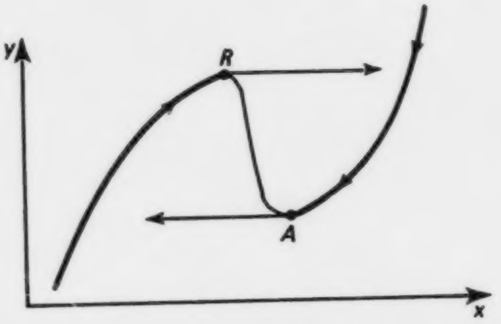

Figure 10. An auto-oscillating regime. A generator of discontinuous oscillations.

In the strict mathematical sense this example was carefully studied in the works of van der Paul, Andronov and others. For our purposes it is important to emphasize that oscillations of this type are not the specific property of radio engineering.

On the contrary, any organism with its clearly periodic alternation of activity and rest is a similar auto-oscillating system. The daily rhythm is a consequence and evolutionary adaptation of an arbitrary, initially auto-oscillating regime.

More complex, ecological systems have adopted (in the middle latitudes) an annual cycle, managing without the external period in the tropics. This attests clearly enough to the endogenic, internal auto-oscillating basis of the adopted (daily, monthly and annual) cycles.

"THE CURSE OF DIMENSIONALITY"

Real biological systems always contain a large number of components of the structural, chemical and morphological type. It seems, therefore, that there must be many variables for the modeling even of not very complex biological systems.

Not by chance do many existing models of ecological systems contain tens and hundreds of variables of the same time scale.

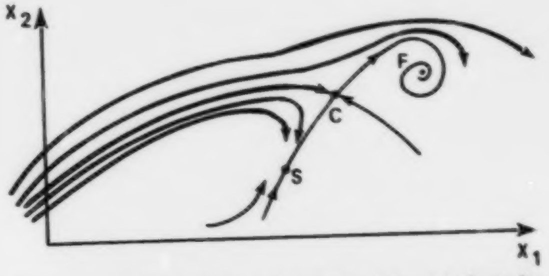

Figure 11. A current pipe. The varying fate of trajectories beginning at near points.

The strictly computational difficulties indeed grow very rapidly as the number of variables grows. This is evident from the following simple discussion. Assume that to study the dynamics of a complex system we calculate on a computer a pencil of trajectories which is "dense" enough so as not to overlook an interesting regime.

Let us assume a net with ten points for each "n" dynamic (phase) variables. Then the total number of trajectories in this current pipe is huge:

$$N = 10^n$$

With the high speed of modern computers of ten billion operations per second ($S = 10^{10}$), in an entire year of continuous calculation (1 year $= 3.15 \times 10^7$ sec) it would be possible to handle a system of the eighteenth order.

A system of the twentieth order would require 100 years.... The fantastic suggestion of increasing the high speed of computers by 10 orders would lead to a system of only the thirtieth order.

All of this means, of course, only one thing: The complete, absolute helplessness of the strictly technical approach, the lack of promise of the methods of direct examination in ecological tasks of even average difficulty.

Only thought, philosophy of life and science can help.

THE BASIC ROLE OF TWO-DIMENSIONAL SYSTEMS

The theory of stability of dynamic systems initially arose in celestial mechanics in the works of Poincaré, Lyapunov and their followers. Subsequent development in the works of Andropov, Chetayev, Bogolyubov, Tikhonov and many others led to the creation of profound qualitative methods of studying general dynamic systems.

For our purposes one simple consequence of the general theory is essential. In order to determine the stability of a stationary state it is necessary to find n characteristic numbers of λ, by solving the age-old equation $\det \| A - \lambda E \| = 0$, where A is the matrix of the linearized system whose coefficients depend, of course, on the parameters of the system.

The characteristic numbers of λ (their n pieces), when n is the dimensionality of the system, which generally speaking are complex, also depend on the parameters. The stability of a stationary state is determined by the signs of the real parts,

$$p = \mathrm{Re}\lambda,$$

of the characteristic numbers.

If all p are negative, $p < 0$, then the stationary state is stable.

However, when the parameters change, the stability may be lost. For this it is sufficient for just one of the p to become zero and then become positive. In all there are just as many numbers as the dimensionality of the system, i.e., there are very many in complex systems. However, "normally" these numbers do not all at once become zero, but only one at a time. Of course, there may be situations in which several p at one time become zero, but for this a very special combination of values of the parameters must be "examined."

This reasoning is not at all strict; it nevertheless shows that more frequent, and thus more important for the applications, is the case when the stability is lost precisely because of one — the only — characteristic number.

This conclusion is very important, for from this it follows that the normal case in the most complex *system is the existence either of two or one significant variable.*

If the real root intersects zero, the one is the significant (unstable) dynamic variable.

But if the complex root becomes purely imaginary, then two significant variables arise.

With subsequent change in the parameters some other pair of variables may lose their stability, but the main occurrences happen precisely with the transition from stability to instability, but not with a complication of the nature of instability.

And it is precisely for these decisive extreme situations that there are serious grounds to doubt that there will be two or even one (in the case of a real root) significant variable.

THE TRANSITIONAL PROCESS OF THE TWO-DIMENSIONAL SYSTEM

What exactly happens after the stability of a stationary point is lost?

In the case of a real root (the unipolar case) there arises the quick motion of the type of the transistion W→A in Figure 1 and the system will simply shift to a new stationary state.

An exactly analogous situation can also arise in the two-dimensional case (the loss of stability of a complex root).

Figure 12 depicts the situation with a "normal" non-extreme value of the parameters of the system. Let the system be in the state S. Let us begin to change the parameters. It may happen that point C will merge with the node S, which will lose its stability and undergo the quick transitional process S→F along the separatrix CF. There will arise a new stationary state — the focus F. It is even easier to imagine the reverse process — the confluence of C with the focus F.

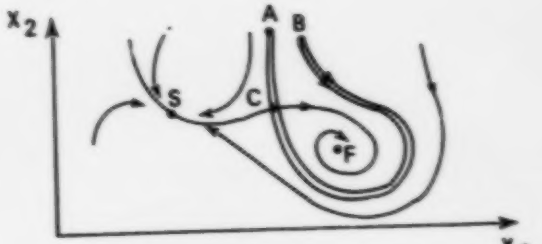

Figure 12. The separatrixes AC and BC isolate the domain of attraction of the focus F. The remaining trajectories bend toward the stable node S.

BIRTH OF THE LIMIT CYCLE

However, in two-dimensional systems there may be a fundamentally new phenomenon — the disappearance of the stationary state and the appearance of a stable periodic regime — the limit cycle.

Let the system whose portrait is depicted in Figure 13 be in the stable state F. The domain of attraction of this state is the interior of the unstable limit cycle C. If when the parameters change the cycle C shrinks into the point F, there occurs *a rigid excitation of oscillations.* The system shifts to an oscillating regime, periodically running over the limit cycle Z.

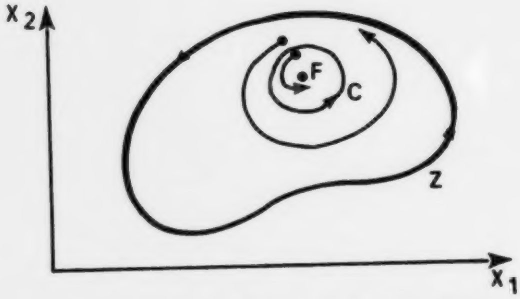

Figure 13. Within the stationary limit cycle is the unstable limit cycle C, which surrounds the stable focus F.

This same effect arises when there is a sufficiently strong phase impact which takes the system beyond the bounds of cycle C. In this instance there also arises a transitional process which does not lead to a new stationary state. As in the first case there arise stable oscillations with a clearly defined period along the stable limit cycle Z.

CONSTANT (FLOW) INFLUENCES

The interaction of man with the environment is not exhausted, of course, by a one-time interference.

More typical is, on the contrary, a constant influence on the system. A typical example is commercial fishing. Annually a certain number of specimens are taken from their populations.

In formal mathematics this is a negative flow in the system. It is influence directly on the system and it can be described by a change in the right side of the equation for x:

$$\frac{dx}{dt}=p+f(x, y).$$

system is the existence either of two or one significant variable.

If the real root intersects zero, the one is the significant (unstable) dynamic variable.

But if the complex root becomes purely imaginary, then two significant variables arise.

With subsequent change in the parameters some other pair of variables may lose their stability, but the main occurrences happen precisely with the transition from stability to instability, but not with a complication of the nature of instability.

And it is precisely for these decisive extreme situations that there are serious grounds to doubt that there will be two or even one (in the case of a real root) significant variable.

THE TRANSITIONAL PROCESS OF THE TWO-DIMENSIONAL SYSTEM

What exactly happens after the stability of a stationary point is lost?

In the case of a real root (the unipolar case) there arises the quick motion of the type of the transistion W→A in Figure 1 and the system will simply shift to a new stationary state.

An exactly analogous situation can also arise in the two-dimensional case (the loss of stability of a complex root).

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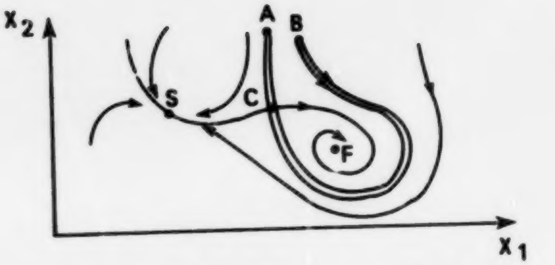

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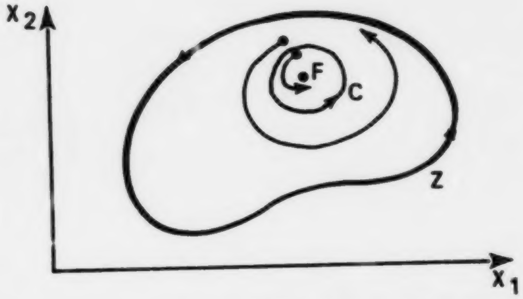

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$$\frac{dx}{dt}=p+f(x,y).$$

This elementary calculation already shows that the constant influence on the system is more complex than the pulsed influence on the parameters, because it leads not simply to a change in the parameter, but to an increase in the number of parameters, to a change in the dimensionality of the structural space.

The constant influence on the environment corresponds to the appearance of an analogous flow current in the equation for y:

$$\frac{dy}{dt} = \varepsilon\,[q + g(x, y)].$$

An example of this influence is the constant discharge of industrial wastes into a river or lake.

An analysis of possible reactions of systems to such influences which is in any way complete is a complex task.

Even a correct posing of the question offers serious difficulties and should be the object of further research.

It is possible nevertheless not to imagine how such research might develop. The point of departure should be the division of systems into stable and adaptive.

This is evident from the fact that given sufficiently small p and q, adaptive systems remain adaptive, and stable systems stable.

This simple consideration (the traditional mathematical argument "on continuity") shows the result of research would be, apparently, a more detailed classification of both adaptive and stable systems. Intuitive considerations give grounds to hope that the modern methods of the qualitative theory of ordinary differential equations are quite sufficient for a complete examination of this problem.

The difficulty will most likely be to give a sufficiently rough classification, to avoid the niceties unnecessary for practical work, to which mathematicians are so inclined.

THRESHOLD INFLUENCES

The theoretical analysis made in this report leads to the conclusion:

The traditional differentiation of threshold and cumulative influences on biological (in particular, ecological) systems has reasonable grounds only under completely defined conditions:

First, the influence is of an instantaneous, pulsed nature.

Second, the times of observation of the reaction are small in comparison to the time of the spontaneous structural reconstruction of the system.

It also follows from the analysis that a more rough and general description of the properties of the system emerges when introducing the concepts of stability (metastability) and adaptiveness.

These concepts follow from the general concept of stability when considering the hierarchy in the structure of real biological systems, which leads to a hierarchy of radically different time scales.

The question is raised of the more detailed classification of systems according to the reaction to constant (flow) influences.

CONCLUSION

The theoretical study of the problem of stability of ecological systems is a task of great complexity and extreme topicality. It requires the application of an entire arsenal of mathematical means obtained in pre-biological natural science, and, of course, the development of new approaches, ideas and methods.

At present the state of affairs in methodological questions is entirely unsatisfactory.

Even well-known mathematical methods are used in ecological studies with insufficient classification. The well-known methods of Lyapunov are well suited for the description of "dynamic impacts" on the ecological system, of the type of the sudden change in the number of one or several species belonging to the ecosystem. However, the structural shifts that correspond to the parametric influence on the system (the change in the water or salt regime, pollution, etc.) do not have in ecological works any adequate mathematical description.

A disturbing break between theory and practice has arisen and threatens to become entrenched. For questions of long-term forecasting, planning and decision-making it is absolutely necessary to know, what happens when there are structural reconstructions in biosystems? Yet theoretical works repeat in quasi-biological terms the well-known mathematical results, and quite frequently with mistakes.

Meanwhile, quite similar problems have been dealt with for a long time and quite fruitfully in other fields of biology — physiology and biochemistry. In a completely different field of knowledge, engineering, also very great is the role of structural reconstructions, a system having a very specific form of the theory of optimum regulation. In the listed areas, independent contacts have long been developing with mathematics, and definite successes have been achieved.

Consequently, a bountiful collection of specific tasks has been accumulated from a broad circle of branches of knowledge, a collection having nevertheless a profound internal common character. The consistent conducting of mathematical research in this area may lead to the development of a sufficiently general approach — a theory of adaptive systems. The deep internal cause for the possibility of such formalization is the morphological heirarchy of complex biological systems, which is dynamically manifested in the kinetic hierarchy, in the set of motions with a radically different time scale. These properties are manifested most vividly precisely at the organism level, being consolidated by billions of years of biological evolution.

It is useful, therefore, even terminologically ("adaptiveness") to emphasize the desire to incorporate "the lessons of history," the desire to carry over to technological and ecological systems the principles of regulation and management, which have demonstrated their effectiveness in rigid tests of natural selection.

Regardless of the possibility or impossibility of constructing a sufficiently general and meaningful mathematical model, the analogy with a whole organism is useful in itself. This analogy puts in sharp relief the question of creating an adequate system of monitoring. Biology leaves no room for doubt about the importance of the nervous system. Without a nervous system (the internal system of "observation and reporting") there could not be either effective management or even the very existence of any complex system.

Another aspect of this analogy is the selection of subsequent variables that correspond to the dynamic hierarchy of the system. There, also, the role of the study of experimental regimes becomes more comprehensible for revealing the hierarchical structure and construction of an adequate system of monitoring on the basis of indicator types, components, and properties.

Such in general outlines are some of the methodological questions raised before mathematicians by the present state of the problems of environmental protection.

ECOLOGICAL MODELING AND ESTIMATION OF STRESS

RICHARD A. PARK

INTRODUCTION

The estimation of ecological stress can be facilitated by a variety of modeling procedures. Such procedures include 1) multivariate analysis, which makes it easier for investigators to perceive the intensity of impact that man has had on the natural environment, and 2) simulation modeling, by which one can gain a better understanding of complex environmental relationships and can therefore make a better prognosis of potential impacts. In particular, simulation modeling has advanced to the stage in the United States where it can be used to examine the potential effects of stresses on both terrestrial and aquatic systems.

In this paper the application of these techniques will be demonstrated by a series of examples taken from the long-term study of Lake George, New York. The study began several years ago with a multivariate analytical survey, followed by the development and implementation of an aquatic ecosystem model; it is presently being completed with the development of a terrestrial ecosystem and land-use model that will be coupled with the aquatic model.

Lake George is of particular interest because it has been a principal site in the U. S. International Biological Program. It is a long, narrow, moderately deep lake (50 km long, 5 km wide at the widest point, and 18 m average depth). The watershed consists of mountainous metamorphic terrane and is approximately 492 km^2, in comparison with the lake area of 114 km^2. Consequently the lake is naturally oligotrophic. However, a heavy concentration of tourists at the southern end of the lake could be expected to have a detrimental impact on the water quality.

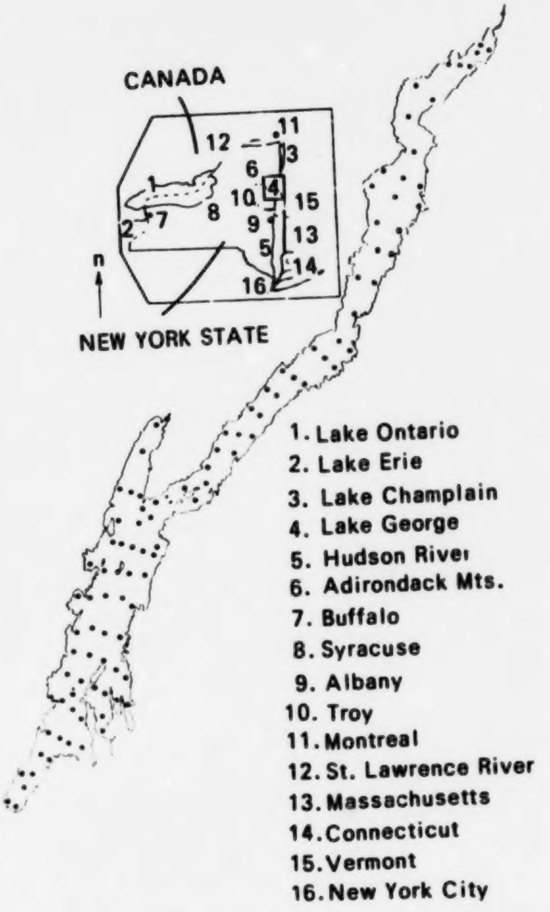

Figure 1. Diatom sample stations, Lake George, New York.

MULTIVARIATE ANALYSIS

In order to rapidly and efficiently determine the stress that tourism has been placing on the lake, multivariate analysis was performed on diatom death assemblages from 125 sample stations located systematically throughout the lake, see Figure 1 [1]. Numerous prior studies of diatoms suggested that they would be suitable indicators of nutrient enrichment, and by studying the diatom frustules contained in the top several mm of sediment a time-averaged indication of impact would be obtained.

The multivariate analytical strategy was designed to obtain the best environmental interpretation [2]. R-mode (variable-by-variable) cluster analysis of the diatom data showed that there was no appreciable redundancy among the diatom types. Q-mode (sample-by-sample) cluster analysis showed that the samples grouped in a number of classes at high levels of similarity, see Figure 2.

Ordination emphasized the environmental gradients among the samples and made it possible to interpret the relationships of the clusters shown in Figure 2. Particular attention was given to the distribution of those diatom types that were known to be indicators of oligotrophic or eutrophic conditions. An example is the distribution of the genus *Cyclotella*, see Figure 3, which in general indicates oligotrophic, or nutrient-poor conditions. By noting the concordant gradients of the various indicator types, the general trend of nutrient enrichment among the samples was determined. A gradational series of patterns was assigned to the clusters to represent their positions along the nutrient gradient in the model, see Figure 4.

These same patterns were plotted on the map of Lake George in polygons enclosing each of the respective sample stations. The result is a map showing the nutrient stress on each part of the lake, see Figure 5. As one might expect, the nutrient-enriched areas are adjacent to the centers of population, moderately-enriched areas are in more sparsely populated parts of the drainage basin, and nutrient-poor areas are in the undeveloped parts.

SIMULATION MODELING

Aquatic

Understanding of the complex relationships of the Lake George ecosystem has been increased greatly by implementation of the aquatic model CLEANER. This comprehensive ecosystem model was developed by 25 investigators in the Eastern Deciduous Forest Biome, U. S. International Biological Program [3]; it is being improved continuously, especially with the addition of environmental-management capabilities [4].

The model simulates 20 compartments, most of which are illustrated in Figure 6. Each of these is represented by one or more equations; mathematical functions are incorporated for each significant ecologic and physiologic process. Such functionality in the modeling ensures generality and permits greater application for management purposes.

CLEANER demonstrates adequate fits of predicted curves to observed data, see Figure 7. Parameter values, such as optimal temperatures and maximum photosynthetic rates, were based on the literature and cooperative IBP studies [5]. No attempt was made to obtain perfect fits by changing these well established parameter values.

Analysis of detailed environmental relationships

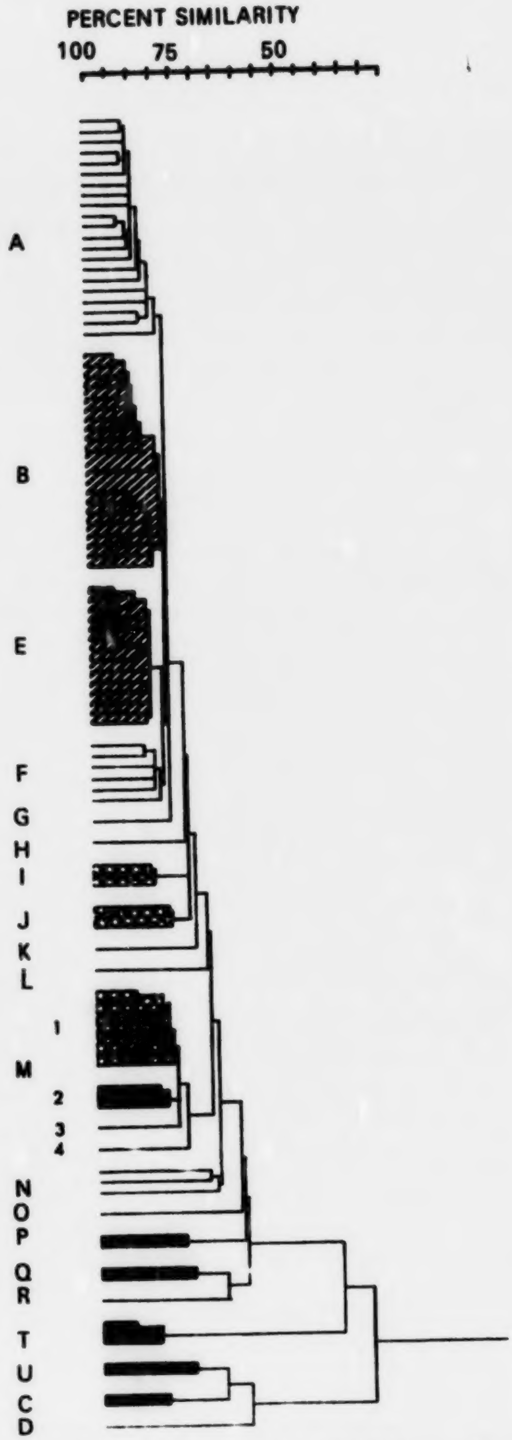

Figure 2. Q-mode cluster analysis of Lake George diatom samples.

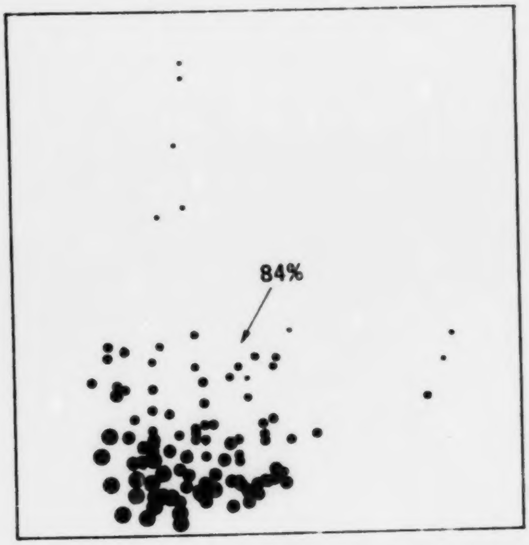

Figure 3. Distribution of *Cyclotella* in ordination model.

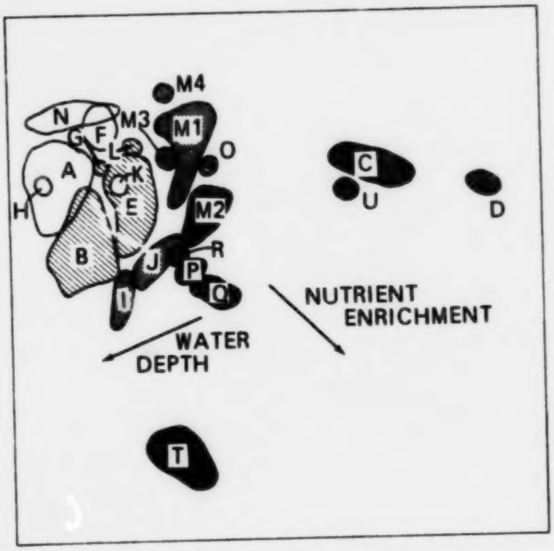

Figure 4. Distribution of clusters in ordination model.

is enhanced by the use of plots showing the predicted time-courses of the modeled process rates [5]. For example, Figure 8 shows that the concentration of orthophosphate in Lake George at any given time is predominantly the result of the biotic processes of uptake by phytoplankton and remineralization by decomposers and animals; the contribution from streams is insignificant. Assuming that the functionalities of the model are reasonably correct, one can infer that decreasing the phosphate loadings in the streams would have little effect on the dynamics of phosphate in the lake.

Perturbation of the driving variables, such as phosphate loadings, results in simulations that estimate the complex effects of environmental stress on all major components of the ecosystem. Most American modelers recognize that the estimations cannot be considered as precise predictions, but they do believe that useful insights can be derived.

Figures 9 through 11 exemplify the simulations that can be obtained in less than five minutes each, using the time-sharing capability of a fast computer available to personnel of the U. S. Environmental Protection Agency from remote terminals anywhere in the United States.

In the first example, see Figure 9, phosphate loadings to Lake George have been decreased to one-fifth of normal. The ecosystem is slow to respond, but blue-green algae and the fish gradually decrease in biomass over a period of several years. In the next example, see Figure 10, a sustained increase in temperature of 5°C results in an increase in blue-green algae and a slight decrease in lake trout. In the last example, see Figure 11, an increase in the extinction coefficient of the water, comparable to the effect of moderate siltation, causes a slight decrease in biomass of net and nannophytoplankton, but again the noxious blue-green algae increase.

The validity and potential applicability of CLEANER is being tested with data from several European lakes. Of particular interest at this time of renewed U. S.-USSR cooperation is the adaptation of the model to Slapy Reservoir, Czechoslovakia. Extensive changes have been made, including development of a two-layered version to represent stratification, changes in parameter values to represent European species, and addition of throughflow terms, see Figure 12.

Terrestrial

In order to fully understand the potential threat of stresses on Lake George and other freshwater ecosystems, it is advisable to utilize terrestrial models as well. This was recognized by the Lake George group, and a case study was recently completed, demonstrating the applicability of combining terrestrial and aquatic models [6].

As a part of the case study, LAND, a model to simulate land-use changes and vegetational succession, is being developed [7]. The model combines the approach to studying land-use changes of Hett [8] and the forest succession model of Shugart and others [9]. However, it is more applicable to problems of environmental impact because it subdivides

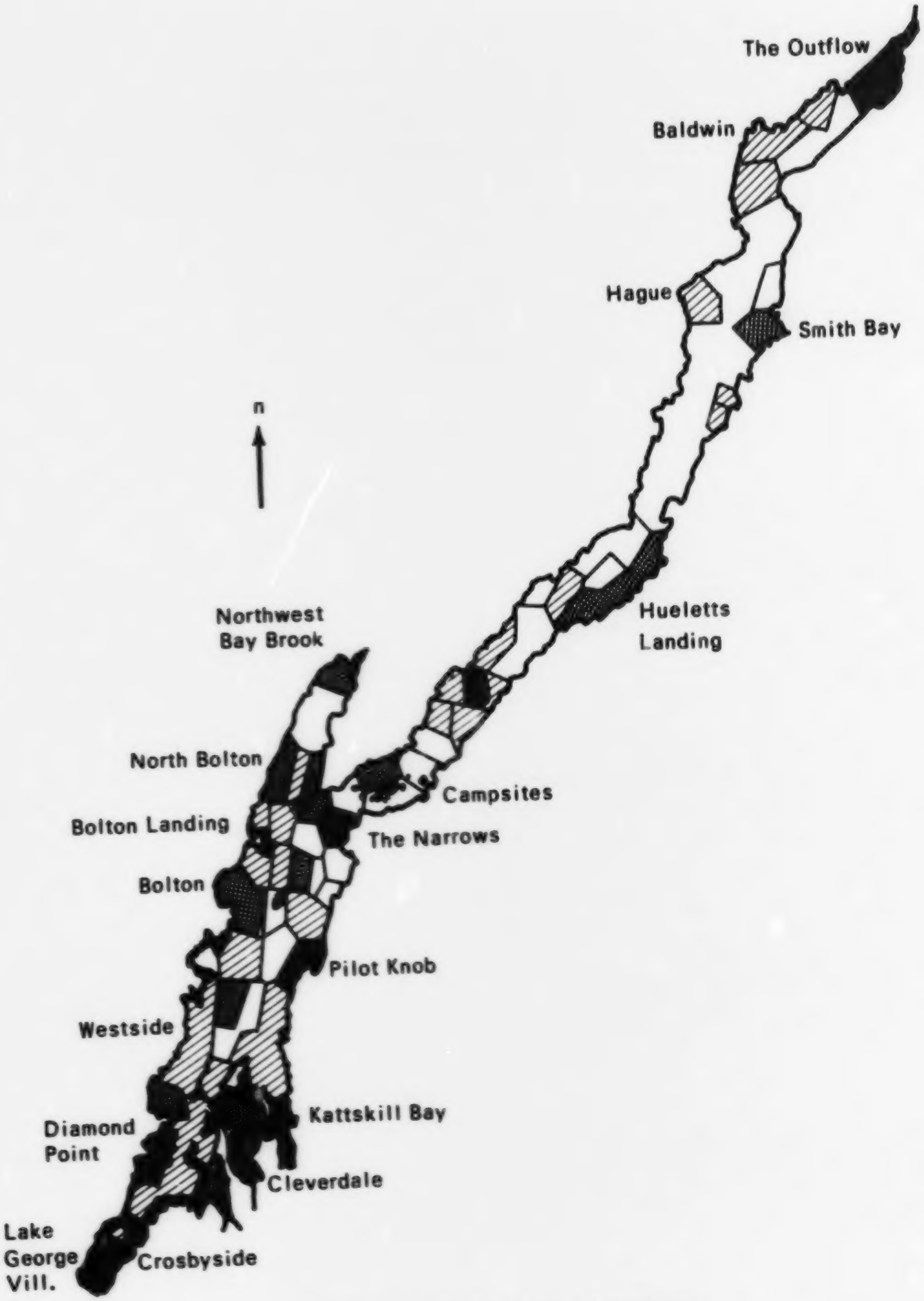
The Outflow
Baldwin
Hague
Smith Bay
n
Hueletts
Landing
Northwest
Bay Brook
North Bolton
Campsites
Bolton Landing
The Narrows
Bolton
Pilot Knob
Westside
Kattskill Bay
Diamond
Point
Cleverdale
Lake
George
Vill.
Crosbyside

Figure 5. Distribution of clusters, Lake George.

a study area into km² cells and considers the site-specific soil, slope, vegetational, aesthetic and cultural characteristics of each. It is anticipated that simulation results can be represented by maps such as those of the calibration data, see Figure 13.

Eventually models such as CLEANER and LAND, as well as hydrologic models, can be coupled to estimate basin-wide effects of environmental stress, see Figure 14. At Lake George, use of information from 7,000 returned questionnaires on environmental perception will permit evaluation of the cultural and economic implications of these environmental effects [4].

SUMMARY

Ecological modeling is useful in estimating the impacts of environmental stresses. A multivariate-analytical approach facilitates interpretation and delineation of biotic responses to stresses such as nutrient enrichment. Aquatic and terrestrial simulation models provide insights into complex relationships, and, through perturbation analysis, permit evaluation of the consequences of environmental impact. The full potential will be realized when these models can be coupled.

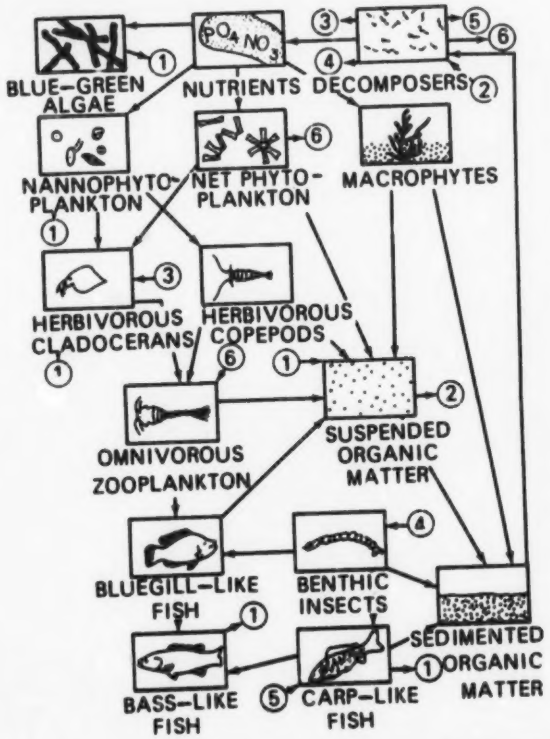
BLUE-GREEN ALGAE
NUTRIENTS
PO4 NO3
DECOMPOSERS
NANNOPHYTO-PLANKTON
NET PHYTO-PLANKTON
MACROPHYTES
HERBIVOROUS CLADOCERANS
HERBIVOROUS COPEPODS
OMNIVOROUS ZOOPLANKTON
SUSPENDED ORGANIC MATTER
BLUEGILL-LIKE FISH
BENTHIC INSECTS
SEDIMENTED ORGANIC MATTER
BASS-LIKE FISH
CARP-LIKE FISH
①
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Figure 6. Compartments in the aquatic model CLEANER.

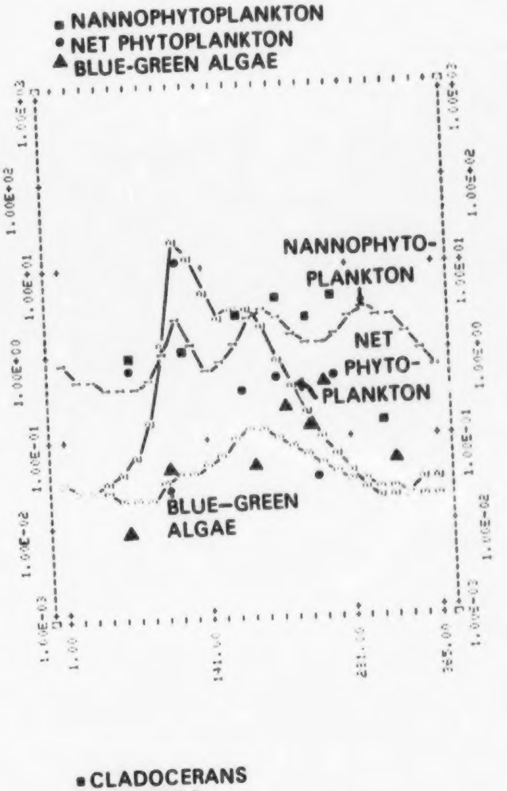

Figure 7. Comparison of predicted and observed values using CLEANER.

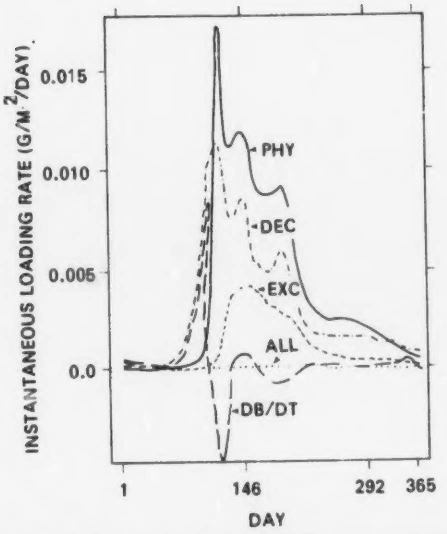

Figure 8. Time-series of orthophosphate process-rates predicted by CLEANER.

ACKNOWLEDGEMENTS

Research supported in part by U.S. Environmental Protection Agency Contract No. 68-03-2142; the Eastern Deciduous Forest Biome, U. S. International Biological Program through the National Science Foundation Interagency Agreement AG-199, BMS69-01147A09 with the Energy Research and Development Agency — Oak Ridge National Laboratory; the Office of Water Resources Research Contract No. 14-31-0001-3387; and the National Science Foundation, Grant No. BMS75-14168.

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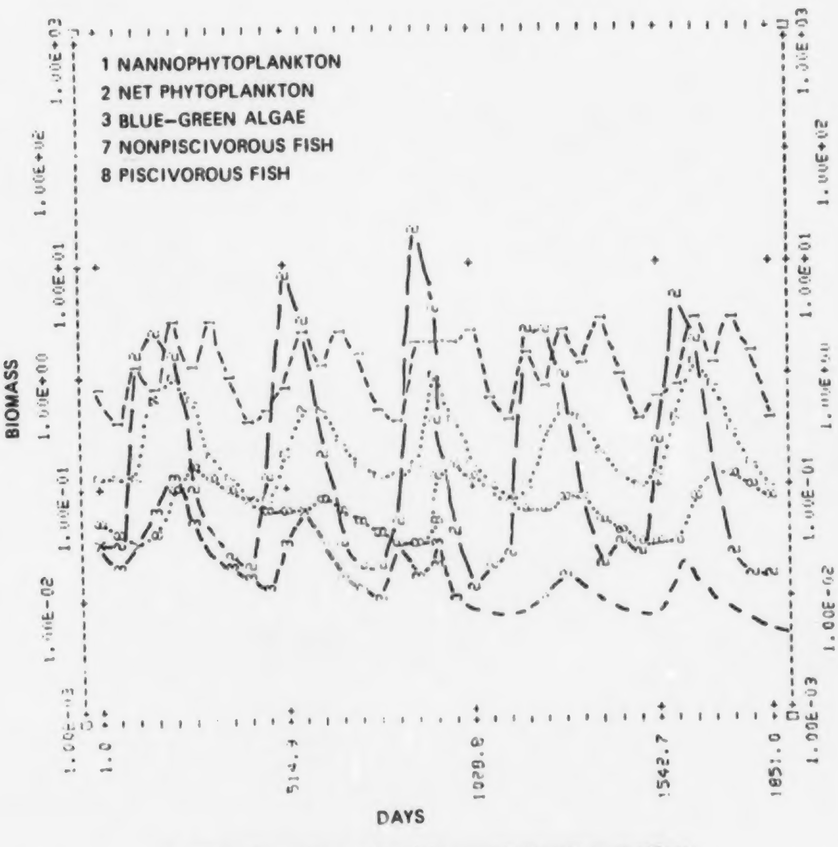

Figure 9. Simulation using 0.2 normal phosphate loadings.

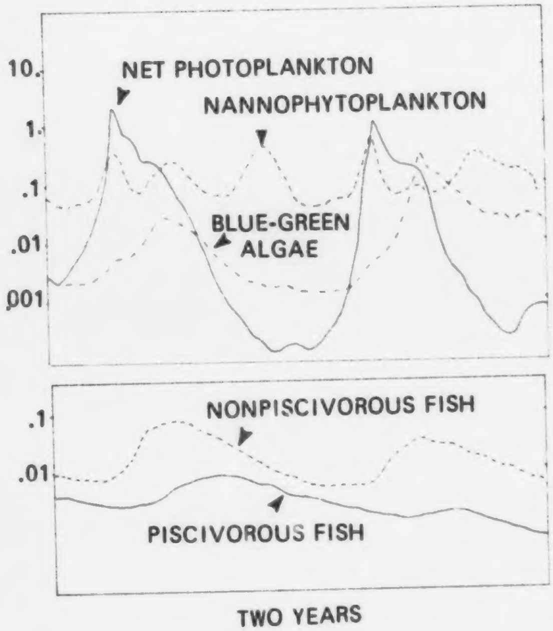

Figure 10. Simulation with temperature increased 5° above normal.

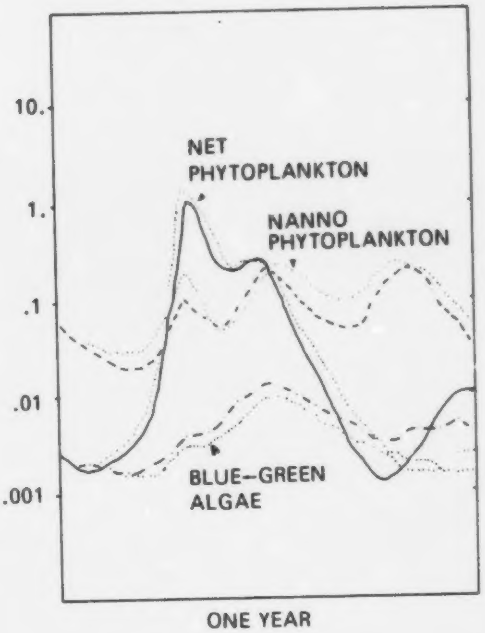

Figure 11. Simulation with extinction coefficient of 0.4 (instead of 0.2 as is normal for Lake George); dotted lines represent normal simulation results.

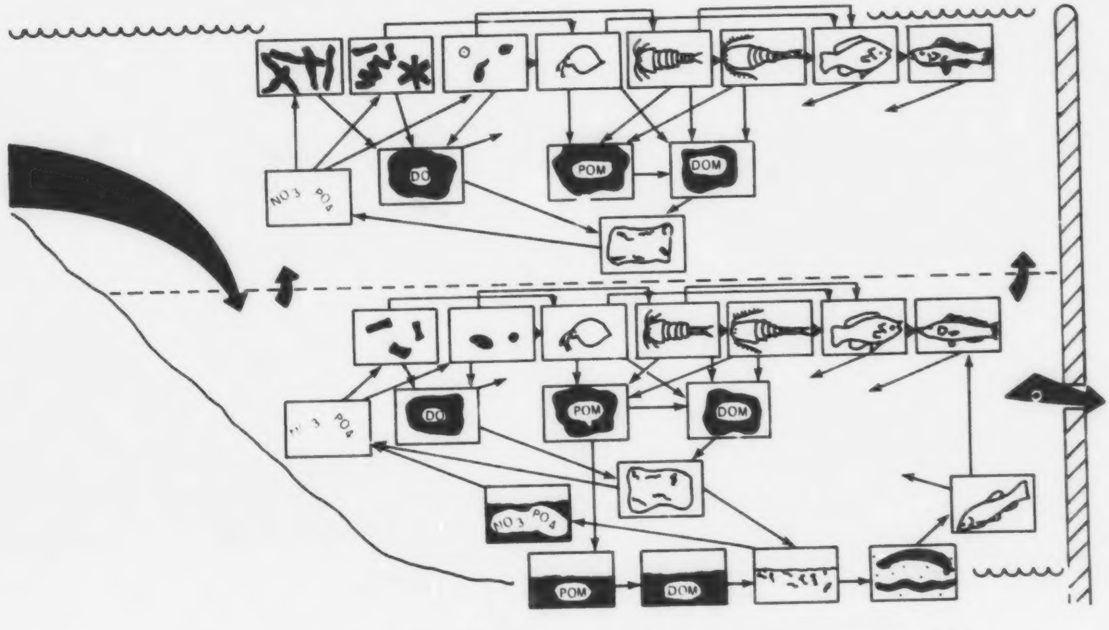
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Figure 12. Structure of version of CLEANER adapted for Slapy Reservoir, Czechoslovakia.

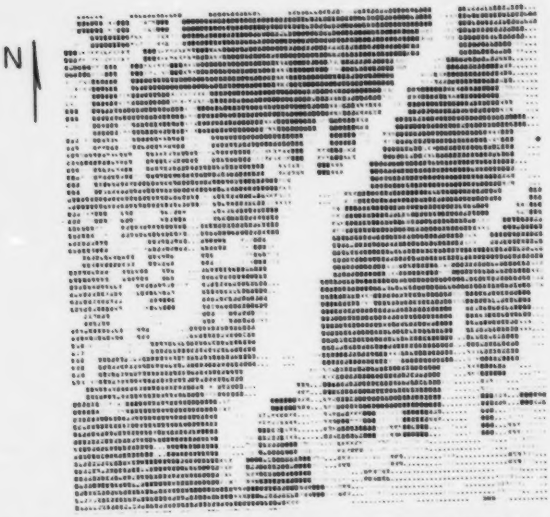

Figure 13. Computer-generated map of natural forests in Lake George region; density of overprint is proportional to percent forest cover in km² cell.

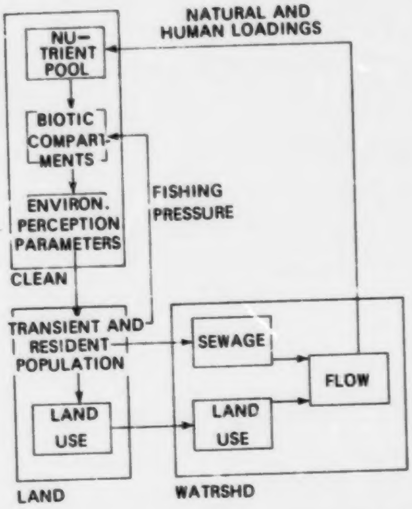

Figure 14. Coupling of simulation models for basin-wide analysis.

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AN ECOLOGICAL-ECONOMIC MODEL OF THE USE OF NATURE

M. YA. LEMESHEV

THE INTERACTION OF MAN AND NATURE

It is well known that the basis for the existence and development of human society is production. Human needs are constantly growing. The satisfaction of these needs gives rise to the necessity for a continuous expansion of the scope of production. Modern production is basically the active influence of man on the natural environment, for the purpose of transforming its diverse resources into consumer goods. Production in the modern world has achieved gigantic proportions and under the influence of the developing scientific-technical revolution continues to expand even further. Production processes now involve not only traditional natural resources, such as soil, water, timber, and minerals, but also resources of the atmosphere, the world, oceans, and outer space.

The achievements of man in "taming nature" in our day are so great that the economic activity of people begins to have a greater effect on the evolution of nature than the natural processes occurring in it. As before, natural conditions have a more important influence on human living conditions, yet the increased productive forces of society give it more and more opportunities to actively change and form the natural environment. The need has arisen to regard the use of nature as a phenomenon of the interaction of man and nature.

THE CONCEPT OF THE USE OF NATURE

In this paper, by the "use of nature," we understand both the direct and indirect influence of man on the natural environment as a result of his activity. This influence may be and actually is both conscious and spontaneous, both purposeful and incidental. We consider it necessary to especially emphasize that here it is not only a matter of the use of material natural resources (power, minerals, raw materials, water, agricultural, etc.), but also a matter of the resources of nature, which meet an entire complex of rational human needs, including their healthy physical and mental life, rest, aesthetic appreciation, creative inspiration and other needs connected with the use of natural wealth. It should be stipulated that here we have in mind precisely the *rational* needs of people, which are caused by physiological, mental and aesthetic demands, and not some needs which arise from a fad, false social prestige, and other regularities of development of the so-called "society of consumption." The processes of the use of nature, on the one hand, should to the greatest possible extent satisfy the rational needs of people, and, on the other, preserve and improve the natural environment as a source of satisfaction of these needs. The achievement of these goals requires the purposeful direction of the processes of the use of nature. The purposeful direction of the processes of the use of nature assumes the use of an entire complex of active measures of a scientific, technical, socio-economic, educational and legal nature. We consider unfounded the opinions expressed by some specialists to the effect that protection of the natural environment requires a limitation of the rates of economic growth. It is not a decrease in the growth of social production, but its further development, the improvement of its structure, equipment and technology with consideration for ecological aspects that are creating a real basis and the necessary conditions not only for protection of the natural environment from pollution and degradation, but also for its planned improvement.

THE INTERDEPENDENCE OF ECOLOGY AND ECONOMICS

The exponential growth of population and industrial production on our planet, given the fixed limits of its biosphere, have at present caused a very close interdependence between healthy socio-economic life of society and the state of the natural environment, i.e., the processes occurring in it. This interdependence is manifested primarily in the fact that the increase in the well-being of people depends on the rates and efficiency of economic development, while economic development itself, to a decisive extent, depends on the scope and level of intensity of the use of natural resources. In turn the possibility of safeguarding the normal biological conditions of the natural environment and the functioning of ecological systems in the biosphere depend on how rationally and in how scientifically substantiated a manner the industrial influence of society on nature occurs.

The economic, social, technological and biological processes in the world surrounding man are now so closely connected and interdependent that there has arisen *the need to regard modern production as the functioning of a complex ecological-economic system, but not to oppose the economic and natural systems with each other.*

THE CONCEPT OF AN ECOLOGICAL-ECONOMIC SYSTEM

In this case, we define an ecological-economic system to be the integration of economics and nature — the interdependent and interconditional functioning of social production and the flow of natural processes in nature and the biosphere in particular. Efficiently organized production has the capability and should not only create material goods and services, but also protect the natural environment from its degradation, maintain and, in a number of instances, restore the ecological balance in nature. In our time the biosphere with its very valuable natural resources is increasingly becoming a very important element of the infra-structure of social production and consumption, which needs its reproduction as does all other (material and nonmaterial) wealth in the system of social production. Analysis of this global process which is occurring in the modern world gave the Soviet scholar, Academician N. P. Fedorenko, grounds to express the idea that we are witnesses to the formation of a new fifth sphere of social production — the sphere of reproduction of natural resources.*

The efficient use of nature under present conditions requires above all an increase in the level of the ecological thinking of specialists and workers of all spheres of activity. The recognition by scientific and practical workers of all areas of the national economy of the need for strict ecological limitations in all technological processes should gradually result in a biologization of social production. In practice this recognition should be reflected in the scientific prediction not only of the immediate, but also of the long-range consequences of all actions undertaken to transform nature and, in particular, to develop modern industrial production. The tasks, apparently, consist not in not using natural resources or curtailing their use, which in practice is hardly realistic, but rather in organizing this use on a scientifically substantiated and rational basis, with maximum economic and social efficiency. The same goes for pollution of the natural environment. Modern production in any form will obviously have wastes for a long time to come, and consequently will, to some extent, pollute nature. Therefore, the problem consists in the scientific determination of the permissible level of pollution. It is known that natural systems have the ability to cleanse themselves, to restore themselves, to change and develop. In order to organize the scientifically substantiated use of natural resources, it is above all necessary to establish the permissible level of pollution of the natural environment and, following that, to use only that production equipment that would ensure growth in products needed by society and, at the same time, would not exceed the pollution level beyond which natural systems are unable to "process" production wastes, lose the ability to restore themselves, are degraded and collapse.

In our time, it is necessary to decisively reject the view of nature according to which it is an "ominous force" against which man must conduct a fierce and tireless campaign. Man and nature are not two opposing forces, but a unified ecological-anthropogenic system, on whose harmonious development the very existence of human society decidedly depends. The cleanness of the natural environment, the protection of the equilibrium of ecological systems, the rational use and reproduction of natural resources today are becoming the most important demands on the development of all production.

On the basis of this it can be asserted that the successful direction of social development and, in particular, of modern social production presumes the integration of methods of directing economic development with methods of directing natural biological processes into a single methodology for directing the ecological-economic system.

THE MAIN TRENDS OF THE RATIONALIZATION OF THE USE OF NATURE

The present level of development of production forces and present notions of the interrelation of the development of nature and society make it necessary to overcome the historically established, purely naturalistic and technical approach to the processes of the use of nature. At present, when evaluating the entire production activity of society, the ecological-economic aspect should assume primary importance.

The use of nature, as a global process of the functioning of the ecological-economic system, should be understood as a purposeful socio-economic activity of society, which ensures:

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*See *Ekonomicheskiye problemy prirodopol'zovaniya* [Economic problems of the use of Nature], Moscow, Nauka, 1973, p. 10.

- —the increasingly complete satisfaction of the growing needs of all members of society through the all-around intensification of the use of natural resources;
- —the protection and extensive multiplication (or improvement of the quality) of natural resources in the interests of future generations of people;
- —the protection of the equilibrium between industrial development and the biological stability of man's natural environment, which guarantees the possibility of the development of civilization and of life itself on earth.

In order to successfully resolve these tasks, it is necessary to clearly understand of what the basic cause of the negative influence of production on nature consists.

WHAT IS THE MAIN CAUSE OF THE DETERIORATION OF THE NATURAL ENVIRONMENT?

The intensification of the negative effects of industrial development on the natural environment, as a rule, is connected with the rapid increase in the scope of this production and with expansion of the sphere of man's interference in the natural processes occuring in the biosphere. However, a more detailed analysis of the cause of the negative influence of man-made activity on natural systems shows that these negative effects are conditioned by the qualitative differences of the circulation of a substance in artificial (economic) systems as compared with natural (ecological) systems. In ecological systems the circulation of a substance is more closed. Here the plant mass, being transformed from stage to stage in trophic chains at the end of the cycle again becomes suitable for feeding plants. In economic systems, however, only an insignificant part of a natural substance is utilized, while the majority of it is returned to the biosphere, having acquired in the production process new, as a rule dangerous, physico-chemical properties. It is this unutilizable part of a substance that creates the stress on nature. Consequently, the main cause of the negative effect of production on the natural environment consists not so much in the scope of production as in the nature of its technologies.

TWO WAYS TO PROTECT THE NATURAL ENVIRONMENT FROM POLLUTION

We can single out two fundamentally different ways to combat pollution.

The first has at present already become quite widespread. This is the treatment of the harmful emissions of industrial and agricultural enterprises into the environment. Further promotion along this line is not very effective, since it does not make it possible to solve the problem fundamentally. This is explained first of all by the fact that with the aid of treatment technology one does not always succeed in completely ceasing the entrance of harmful substances into the biosphere. In the treatment process the conversion of one type of pollution into another often occurs. For example, the replacement of dry dust collectors with wet ones increases the degree of purification of the atmosphere, but simultaneously increases the pollution of waters. The construction of reliable treatment technology is very expensive. Moreover, it occupies more land areas, creates the new problem of disposing of solid wastes and sediments from treatment systems, and so forth. All this sharply decreases the effectiveness of this means of preventing pollution.

The second way is more radical and at the same time economical. The point of it is to develop technological production processes which would simulate natural processes to the maximum possible degree. It is a matter of creating nonwaste-producing (in the initial stage low-waste producing) production technologies which would make it possible to utilize all (in the initial stage many) substances harmful to the biosphere. At present the second way has not yet been widely developed. The main reason for this situation is the absence of a calculation of the economic damage from environmental pollution and as a result this means is not able to compete with the first one. The preliminary evaluations we have made provide grounds to think that the calculation of the damage from environmental pollution makes the second way more economical and consequently preferable.

EVALUATION OF ALTERNATIVES

At present an increasingly greater number of specialists, including economists and engineers, understand that the stability and reliability of natural systems have their limits and therefore there must be a determination of the permissible bounds of the effect of modern production on the biosphere. However, economics also has, alas, only a limited "reserve of stability." It develops according to its own laws and cannot bear any demands from ecology. These demands at times are so severe that their observance leads to the unprofitability of production, which is, as a rule, equivalent to its curtailment.

Under these conditions there must be a search for compromise solutions which would make it possible to protect the natural systems and develop production. In other words, there must be a search for the economic optimum of pollution and level of purification of the natural environment.

In modern economics the more complete utilization of basic raw materials is recognized as efficient only if the expenditures for additionally obtainable output (S_1) are less than the expenditures for obtaining an analogous output in rival technological processes (S_2) (when using other types of raw materials), i.e., the condition of the feasibility of raising the completeness of utilization is the inequality

$$(S_2 - S_1) > 0. \tag{1}$$

Since relatively few utilizable materials are usually contained in production wastes, nonwaste-producing technologies often seem economically less efficient than technologies oriented on the use of more concentrated raw material sources. *Thus, the colossal resources of sulfur dioxide in gaseous emissions of thermoelectric power stations are at present not utilized, since its low concentration makes these gases incapable of competing with other sulfur-containing raw materials.* Morover, the determination of the economic effectiveness of nonwaste-producing technologies according to expression (1) under present conditions should be recognized as unacceptable. In calculations of this time it is absolutely necessary to consider the extent of the economic damage from environmental pollution in comparable alternatives, i.e., the condition of the feasibility of raising the completeness of the utilization should not be the inequality (1), but the inequality

$$(S_2 - S_1 + \Delta R) > 0 \tag{2}$$

(ΔR is the decrease in economic damage from environmental pollution when using nonwaste-producing technology).

It is easy to notice that calculation of the damage from environmental pollution results in a significant expansion of the bounds of the economic feasibility of using nonwaste-producing technologies. Now nonwaste-producing technology is economically efficient even when the cost of the obtained output according to this technology is higher than in rival alternatives. *It is necessary only that the "overexpenditure" of production costs and capital investments be less than the savings from the decrease in the damages from environmental pollution.*

Calculation of the economic damage from environmental pollution by production wastes inevitably entails an examination of the customary concepts of "useful" and "harmful" components of the material-energy flow in modern production. Since the utilization, for example, of ash and sulfur, which are contained in fuel coal, is economically advantageous, there are no grounds to consider these substances only as "harmful admixtures" and appraise the usefulness, for example, of extractable coal in all instances in inverse proportion to its content of ash and sulfur.

For economic substantiation of measures to prevent economic damage from pollution and losses of natural resources the method of development of an intersectorial balance of production and distribution of the gross national product (of the input-output type) can be used. In calculating according to such a balance with the given structure, given volumes of finished products of the sectors, as well as the given volumes of permissible emissions of pollutants, it is possible to obtain the following indicators which characterize the development of production and state of the natural environment:

—volumes of gross product output and volumes of capturable pollutants connected with them;

—sectorial pattern of pollution of the natural environment;

—proportion of captured valuable products in the meeting of the overall need of the country for these products.

With the aid of the alternative calculations by the intersectorial balance method, it is possible to study: a) the correlation of the volume of the national product and total expenditures for protecting the environment with the given permissible emissions; b) the change in the pattern and volume of the gross product, depending on the change in permissible emissions; c) the change in the pattern of expenditures of sectors for the elimination of pollution, given a change in permissible emissions; d) the change at the same time in the total volume of expenditures on the elimination of pollutants. Such calculations can be made given the following basic data, which must be prepared on a sectorial basis: 1) the emission of a particular polluting substance per unit of product output in each polluter-sector; 2) expenditures of sectors producing treatment technology for capturing a unit of a specific pollutant; 3) permissible emissions for specific pollutants on a national scale.

By having this information available, decision-making units may, on an economically substantiated basis, implement a policy of developing and incorporating low-waste producing and nonwaste-producing technologies with due regard for the demands of ecology and the available labor resources and capital investments.

ECONOMIC EVALUATION OF THE DAMAGE FROM POLLUTION

The practice of many industrially developed nations shows that the economic damage from pollution of the natural environment amounts to billions of dollars a year. Its correct calculation will make it possible to work out on a more substantiated basis the strategy of development and incorporation of "clean" industrial technology both within individual countries and within international cooperation on problems of protecting the natural environment from pollution. For these purposes it is necessary above all to discover the most substantial *types of damage* done by environmental pollution. The list of them is obviously very large.

For example, an increase in the content of dangerous substances in the atmosphere causes:

—accelerated corrosion of fixed capital and materials;

—a decline in the yield of agricultural crops and a loss of their nutritional value;

—deterioration of the state of available timber, a lowering of the productivity of timber and quality of wood;

—an increase in human morbidity and, consequently, a loss of work time.

This list could obviously be considerably lengthened. Analogous types of economic damage are caused by pollution of water and soil resources. Moreover, environmental pollution causes psychological, aesthetic and other types of damage, which are more difficult, and at times even impossible, to express in economic terms, but they should be considered.

The determination of the economic damage done by each individual type of pollution will make it possible to establish specific disincentives (payments for polluting) with respect to enterprises permitting this pollution. These assets should be concentrated in the hands of the government or regional administrative organs and be expended for putting into operation projects for the protection of the natural environment and, in particular, for establishing incentive subsidies to enterprises introducing new equipment that makes possible the complete utilization or elimination of harmful wastes and which do not allow pollution of the natural environment.

Preliminary calculations indicate that with activity organized on a planned basis within a single country or a group of countries, environmental protection is justified economically and can become a highly efficient sphere of application of social labor, since the savings from the elimination of the damage caused by pollution are higher than the expenditures necessary to prevent pollution.

AN ECOLOGICAL-ECONOMIC MODEL FOR DIRECTING THE PROCESSES OF THE USE OF NATURE

A Basic Scheme

Soviet economists and other specialists have been occupied for a long time with elaboration of the problems of the optimal utilization of the resources of the natural environment. Thus far some results have been obtained which may be of interest to specialists of other countries, and in particular to the U. S. specialists who are participating in the Soviet-American program of environmental protection.

In particular, the author of this report has developed an ecological-economic model of the use of nature (see Figure 1). The point of this model is that in it, and simultaneously in the intercoordination, are reflected the processes occurring both in the economic and in the ecological subsystems. This makes it possible to make decisions ensuring that the maximum economic output is obtained in production and that the destructive effect of industrial technology on nature is not permitted.

Socialist society with its humanitarian goals cannot agree to a curtailment of production. Moreover, as a rule, it cannot agree either to a decrease in the growth rate of this production, since this would automatically result in a decline in the growth rate of the well-being of the people. Society likewise cannot agree to a reduction in the economic effect of production.

On the other hand, society cannot permit the achievement of production growth and the increase of its economic effect through the depletion of natural resources and the pollution of the natural environment, since not only production development, but also the existence of life itself on earth depend on their status.

Under these conditions only one path remains possible—the path of joint optimization of the economic and ecological subsystems, or more specifically, insurance of the growth of social production and the increase of its efficiency given rigid ecological limitations that will not permit the ruin and degradation of the natural environment. The stipulation should be made that in specific cases (in individual regions or industrial centers) it will be necessary to limit ourselves to maintaining the achieved level of production and its economic effectiveness with the purpose of protecting the ecosystems experiencing the negative influence of this production.

The above-offered basic model of the direction of the ecological-economic system makes it possible to choose the optimum solution both from the point of view of economics and from the point of view of ecology. Into the input of the model are fed a large number of different means (alternatives) of the utilization of natural resources. As a result of the interaction of social production and natural systems (processes) at the output we have results of

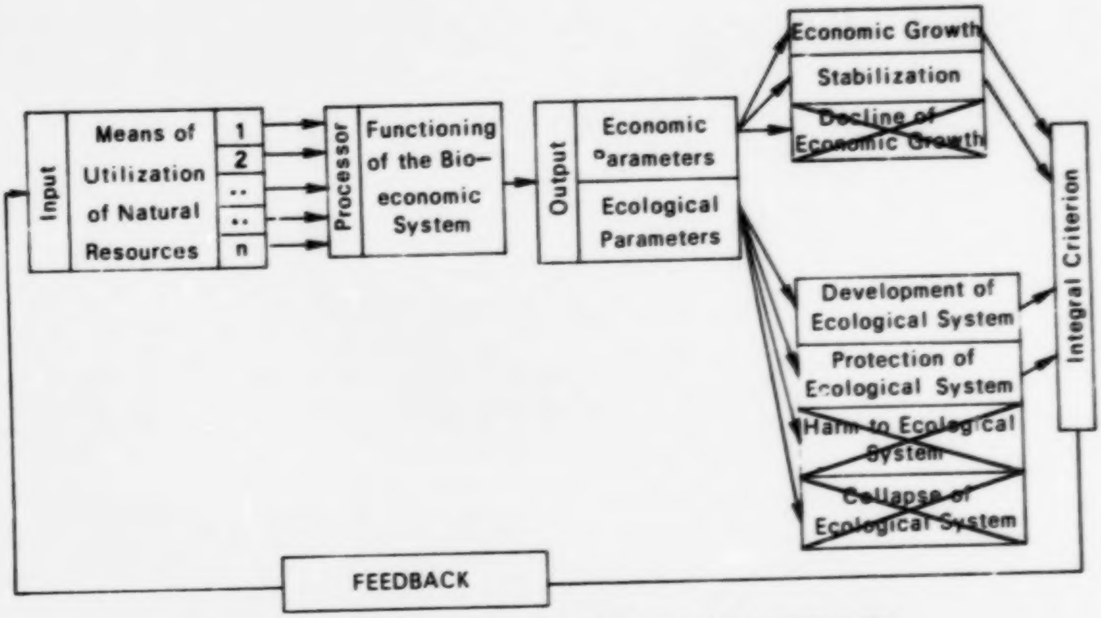
Input
Means of Utilization of Natural Resources
1
2
..
..
n
Processor
Functioning of the Bio-economic System
Output
Economic Parameters
Ecological Parameters
Economic Growth
Stabilization
~~Decline of Economic Growth~~
Development of Ecological System
Protection of Ecological System
~~Harm to Ecological System~~
~~Collapse of Ecological System~~
Integral Criterion
FEEDBACK

Figure 1. Basic model of the direction of the ecological-economic system.

an economic and ecological nature. Any means (alternative), examined by the project, of the utilization of natural resources, no matter how high a level of economic growth it promises, should not be included in the plan if the economic effect is accompanied by the degradation or ruin, the collapse of the ecological systems or important parts of them. Likewise not to be included in the plan is the means (alternative) of the utilization of natural resources which ensures the protection or even development of the natural ecological systems, but entails a curtailment of production or a decline in its economic effectiveness.

Public ownership of the means of production in our country, the concern of the socialist government for the welfare of all members of society, high-quality social production, the planned nature of its development make it possible to organize the purposeful direction of economic development with due consideration for the ecological aspects.

MATHEMATICAL SIMULATION MODEL OF THE LAKE BAYKAL REGION AS A METHOD FOR COMPREHENSIVE ANALYSIS, LONG-TERM FORECASTING AND DETERMINATION OF THE PERMISSIBLE YIELDS OF THE INFLUENCE OF NATIONAL ECONOMIC ACTIVITY ON ENVIRONMENTAL QUALITY AND THE STATE OF ECOLOGICAL SYSTEMS

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INTRODUCTION

The proposed model is the realization of the program of research, which we described at the first Soviet-American symposium on the comprehensive analysis of the environment [1]. Our purpose in studying the Lake Baykal region is the development of a method for the long-term forecasting of the change in the parameters of the state of the environment — indicators of the influence of human activity — given different variants of the development of the national economy in this region.

Without dwelling here on the methodological question of developing criteria of the general evaluation of the influence of man's activity on the environment, let us note that this work is now being conducted by many organizations, in particular the UN European Economic Council and SCOPE of the International Union of Scientific Societies [2]. Devoted to the methodological questions of determining the permissible yield of pollution on the environment was work [3], which was reported at the first Soviet-American symposium.

In this report we will concentrate our attention on specific problems of the over-all, comprehensive analysis of man-made pollution of the environment on a regional scale.

As we noted earlier [1], the problem of pollution should be treated on a sufficiently broad basis, within the framework of the general tasks of the rational use of natural resources. Here, however, it is necessary to act with moderation, for a too extensive and general approach, in particular in the initial stage, threatens the constructiveness and practical usefulness of the results. Following the example of [4,5], we will examine pollution — the byproduct of normal economic activity — within the sufficiently broad and, at the same time, quite specific, quantitative framework of the system of the "intersectorial" balance.

Although we did not use the term "comprehensive analysis," below we will discuss basically a synthesis, a model approach to the solution of the problem.

This is connected with the fact that the very complex system in question — economic activity $\rightleftarrows$ environment — does not yield to the classical scheme of analysis, which is understood as the dismemberment of the whole into smaller parts and their study in isolation. In order to study such complex dynamic, nonlinear and stochastic systems, which are described by a large number of variables (having feedbacks, temporary setbacks and even breakdowns), a methodology has been developed, the basis of which is systems analysis and mathematical simulation modeling [6-8]. However, a serious defect of simulation modeling is its "complexity" — as a rule, a large, boundless number of variants of the types of connections and parameters ("the curse of multidimensionality"). Evidently, a reflection of this circumstance is the well-known statement of the representatives of the school of J. Forrester and D. Meadows: "It is easy to create a complex model, and hard to create a simple one," [9].

In our opinion, a significant simplification of the methodology of simulation modeling that is especially evident when analyzing pollution is the application of the mass balance approach in the spirit of W. Leont'yev [4]. Thus, in short, our approach can be characterized as the incorporation of the method of "intersectorial" balance in the methodology of mathematical simulation modeling. It is a multidisciplinary quantitative method that is aimed at the study of complex systems without complete knowledge of them, at the prediction of their behavior under changing conditions and in the final analysis is oriented toward the use of decision-making units for management (in some sense the optimal management) of such systems (in particular, the system: economic activity $\rightleftarrows$ environment).

In this sense we will discuss below the "comprehensive synthesis" of the problem of environmental pollution on a regional scale.

GENERAL DESCRIPTION OF THE MODEL

The mapping of the Lake Baykal region, see Figure 1, as a relatively closed economic-ecological system, was carried out by us [1] on a basin-wide, hydrological basis.

The numerous studies on ecology, economics, hydrology, hydrochemistry, geophysics and meteorology, which are being conducted on the territory of this region, provide information which in principle makes it possible to synthesize the economic-ecological model of the region as a whole. However, on the way to the complete realization of this program, it was discovered that there are significant difficulties connected with the fact that the studies mentioned are being conducted unevenly, in the sense that even though good information is being refined, at the same time some processes have gone almost unstudied. These circumstances will be clarified in the course of describing the model.

The proposed model is the first version of the model of the Lake Baykal region, not all the parts (modules) of which have been developed to the same extent. However, it is important to note here that, in itself, the fact of the discovery of holes in our understanding of the region as an economic-ecological system became possible as a result of constructing this model, which thus made it possible to refine the program of subsequent studies of the region. Moreover, the modular principle we have adopted for constructing the model, when this model consists of sectors and subsectors that are relatively independent and are simply being connected together, makes it possible to alter the individual parts of the model without significant alterations to the other parts.

The prediction of possible changes in the ecological systems (biogeocenoses) of the region under the influence of economic activity, and the use of this prediction by decision-making units require:

—the breakdown of the region into territorial subsystems relatively uniform in physico-geographical conditions (which is responsible for the relative similarity in the ecological systems);

—the construction of models of economic activity and its consequences for the environment (for example, pollution) for each of these territorial subsystems and the region as a whole;

—an evaluation of the changes in the environment under the influence of economic activity.

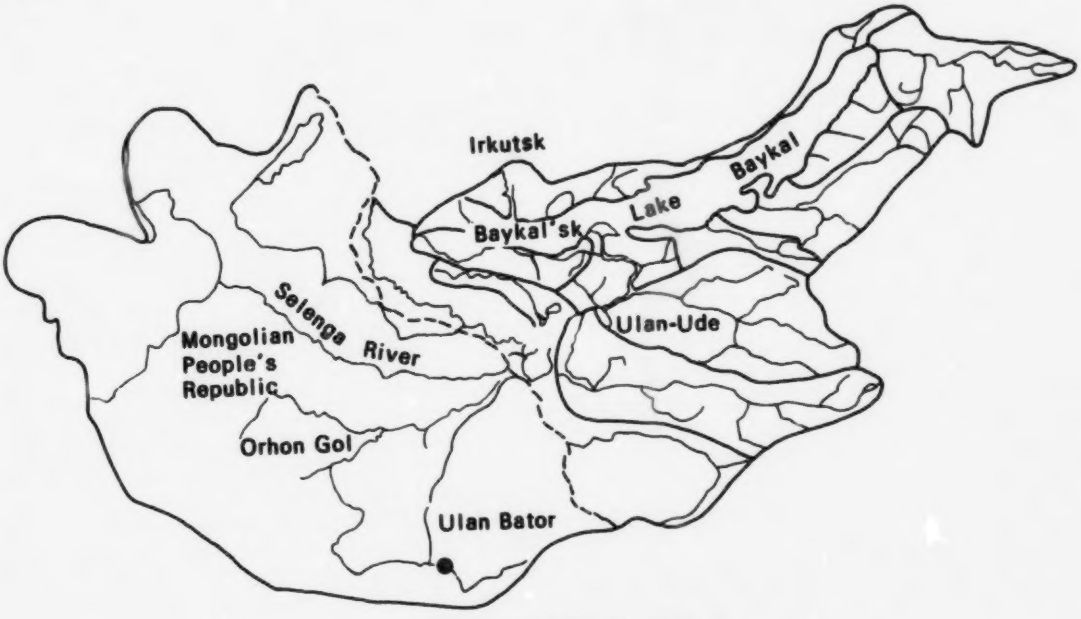

Figure 1. Lake Baykal region.

The breakdown of the region was also previously described by us [1], see Figure 1. The solution of the second problem at present is being concluded, and below we will cite the description of a part of the problem, namely the model of the distribution of pollution in the environment (atmosphere, hydrosphere, biota). The solution of this problem also has an independent significance, since it makes it possible to make a preliminary comparison of different variants of the development of the economy according to the damage caused by environmental pollution. Finally, the methods of ecological-economic evaluation of man-made pollution are being developed, and some reflections on this part of the problem will also be cited below.

A time horizon equal to 20 years was selected for the model. Such a choice makes it possible to reveal the important long-term aspects of the interaction of economic activity and the environment. On a time scale, it can be considered as intermediate between short-term, strictly inertial, yet quite reliable prognostic schemes and very long-term schemes (in the spirit of Forrester-Mesarovich), which include significant reconstructions of the socioeconomic structures. Obviously, 10 to 20 years is a period, during which the economic system, while undergoing changes, still does not entirely lose its "inertia," and therefore the model can be considered relatively reliable.

It is appropriate to make the following remarks. Without going into the strict logical substantiation of the problem of the long-term prediction of such a complex system, such as is the system: economic activity $\rightleftarrows$ environment [10,11], we should nevertheless have a clear understanding of two circumstances.

First, it is necessary that the prediction not contradict the requirement of verifiability [11]. Otherwise the prediction may degenerate into purely deductive constructions that are little connected with the analysis of truly observable phenomena.*

Second, the problem of long-range forecasting should be examined together with the tasks of long-term planning (under the conditions of a planned economy this is especially evident). Otherwise it is possible to fall into an incongruous closed circle, having begun to predict not that which will occur in specific proposals, but that which will be resolved by planning organs.

When constructing the model and describing the functional interconnections between its parts (modules) we use the methods and means of "system dynamics" and the DYNAMO modeling language [12].

However, this method, while having significant merits (precision of methodological premises, absolute clarity of language, a number of advantages of a calculation nature), unfortunately is poorly suited for the analysis of diffuse systems. It assumes that the distribution of the interacting objects in the examined area of space is uniform, i.e., the models contain derivatives for time, but do not contain derivatives for space. This occurs if the "concentrations" of the interacting objects (for example, the concentration of pollution in water and the density of the distribution of water organisms in the examined area in the entire region or its subregions) are quite rapidly equalized through diffusion or displacement. Such models, as is known, are called point models (since they can be attributed to any of the points of the area).

In our case it is necessary to consider the spatial effects and spatial dis-aggregation of the variable; therefore, in addition to derivatives for time, derivatives for space appear, and the model reduces to a system of equations in partial derivatives. Such models are called diffuse.

Since the study of diffuse systems is connected with great mathematical and computational difficulties, a reliable result can be obtained only in those instances when the behavior of the appropriate point models is well known.

Therefore, we use the following method. At first the point models are studied using the methods of system dynamics. Then we determine the dimensions of the area in which the system can be considered uniform. Then the interaction between different uniform areas is studied.

In essence, the breakdown of the region into subregions is a rough (to a zero approximation) solution of this task. The specification of this breakdown would be the next approximation.

As was indicated above, within system dynamics modeling we use the mass balance approach [4,5]. In its more complicated form (the multiregional and dynamic version) its method makes it possible to explain the spatial distribution of the production and consumption of various commodities, including the "production" and "consumption" of pollution. Ordinary economic statistics deals with commodities having market values. Therefore the production and consumption of lead in industry, for example, are a part of the ordinary statistics, while the same lead and carbon monoxide, which are "produced" by motor vehicles and "consumed" in particular by people, are not. These questions face us squarely when we move from explaining pollution to trying to prevent it. The calculations by the model of the "intersectorial" balance make it possible to evaluate the different methods of combatting pollution.

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*Sharp criticism of this direction in econometric modeling (i.e., in the area close to our set of questions) was given by W. Leont'yev [13].

STRUCTURE OF THE MODEL

Serving as the basis of the model are the following inventory and functional modules:

Inventory of the sources of pollution of the atmosphere, streams of water, the soil within the framework of the model of the intersectorial balance. The reduction of the inventory to a "standard" form.

Module of the diffusion of pollution in the atmosphere. According to data on sources, and meteorological data on the wind rose and precipitation, a calculation of the space-time distribution of pollutants in the atmosphere and an evaluation of the rate of movement of pollutants from the atmosphere into the underlying surface, and a space-time picture of the density of the distribution of pollutants on the land are calculated.

Module of the movement of pollution from the land into neighboring streams and the atmosphere; absorption by the biota is possible. According to data on the space-time distribution of pollutants on the land their transfer to water flows in calculated, and the reverse transition into the atmosphere and the absorption by dry-land biogeocenoses are also evaluated.

The transfer of pollution by water flows. By having information on the sources of emissions into streams and knowing about the entrance of pollution into streams from corresponding sectors of the catchment, we calculate the space-time picture of the distribution of pollutants in rivers and evaluate the entrance of pollution into Lake Baykal.

Evaluation of the zones of "influence" of major sources and the structure of the fields of pollution of Lake Baykal. Having data on the primary sources and data on the entrance of pollution with rivers, as well as information on the transfer of pollutants from the atmosphere into the surface of Lake Baykal, we evaluate the zones of influence of major sources and calculate the picture of the space-time picture of the fields of pollution.

Prediction of the state of natural ecosystems. According to the results of the calculation of the distribution pollution in the atmosphere, water and soil, we evaluate and predict the possible changes in the functioning of dry-land and water biogeocenoses.

Module of the evaluation of the damage from pollution and optimization of the use of the resources of the ecosystems of the region.

We examine four basic quantitative components of the vector of damage:

—damage to fishing;
—pollution of large masses of water (in this case the water is regarded as an industrial resource);
—recreational damage, connected with the losses or decrease in incomes from the activity of sanatoriums, holiday hotels, etc.;
—decline in the variety of present species.

This last module is, at present, the least developed. We assume that the optimum policy of the exploitation of the resources of the region can be found as the optimum management of some function of the global "utility" of the region; some reflections on this notion will be given below.

As was indicated above, we studied point models using the methods of system dynamics. As an example there is cited, in Figure 2, a generalized scheme of the spread of pollution in the Lake Baykal region (we used the symbols of the method of system dynamics [10]. Let us explain the figure.

The dynamics of the pollution of the atmosphere are defined by the intra-regional sources, the transfer from neighboring regions and global transfer, as well as by the processes of transfer, the physicochemical processes of the conversions and fallout of pollution from the atmosphere ("self-purification" of the atmosphere).

Precipitation onto the underlying surface leads to its pollution (the areas of river catchments, the soil and, indirectly, the water of the lake are polluted). The life span of pollutants in the atmosphere depends, evidently, on a large number of factors, among which the amount of rainfall, which determines the "wet" movement of pollution, is one of the most important.

Some pollutants (for example, mercury) may evaporate from the underlying surface into the atmosphere.

The washing of fallen pollution into streams depends on the nature of the underlying surface. We will differentiate the following types of underlying surfaces:

—the lake surface,
—forest tracts,
—meadows,
—plowland,
—eroded lands, and
—urbanized territories.

The nature of the underlying surface (the time horizon of the model is 20 years!) may change as a result of economic activity (lumbering or tree planting, the plowing of land, urbanization, etc.).

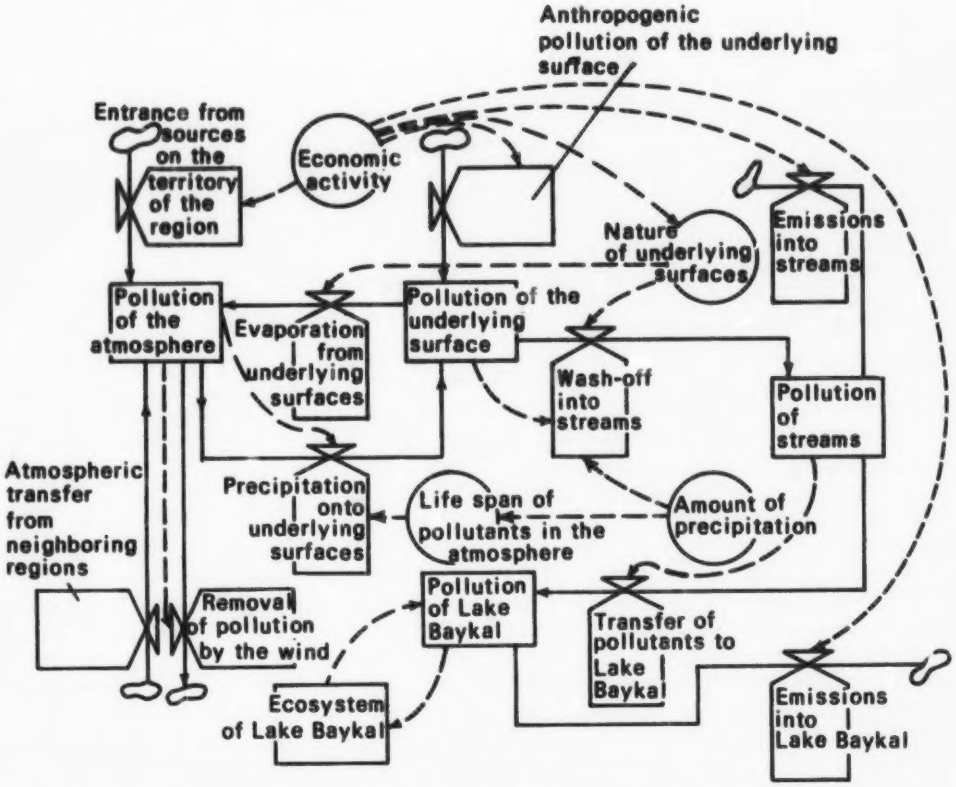
Anthropogenic pollution of the underlying surface
Entrance from sources on the territory of the region
Economic activity
Nature of underlying surfaces
Emissions into streams
Pollution of the atmosphere
Evaporation from underlying surfaces
Pollution of the underlying surface
Wash-off into streams
Pollution of streams
Atmospheric transfer from neighboring regions
Precipitation onto underlying surfaces
Life span of pollutants in the atmosphere
Amount of precipitation
Pollution of Lake Baykal
Removal of pollution by the wind
Transfer of pollutants to Lake Baykal
Ecosystem of Lake Baykal
Emissions into Lake Baykal

Figure 2. Generalized scheme of the spread of pollution in the Lake Baykal region.

The pollution that entered the streams is carried into the lake, undergoing, depending on the type of pollution, different types of processes of transformations (the "self-purification" of streams). In Lake Baykal there are formed the space-time fields of the pollution, which interact with the biota.

Let us proceed to a description of the individual modules.

Inventory of the Sources of Pollution

For the first version of the model we have sufficient information on the level and structure of economic activity in the region and, in particular, on the magnitude of the basic emissions of pollutants into the environment. Therefore it was no problem to take an inventory of these emissions for the region as a whole and for its individual subregions (where this made sense).

More complicated was the task of reducing this inventory to some "standard," yet at the same time sufficiently flexible form (for convenience of the examination of alternative variants). It is likewise necessary that this form of inventory be simply connected with the system of equations of the intersectorial balance of the flows of substances; with the multiregional dynamic system of the Leont'yev type. In the long-range future not only the level, but also the type (the matrix of "technological" coefficients) of the economic activity of the dynamic region of Lake Baykal cannot but change, therefore a reliable system for the long-range prediction of the emission of pollution into the atmosphere is possible only on the basis of the system of equations of the intersectorial balance.

The development of the format of the inventory is currently being completed and includes the breakdown of pollution according to:

—the types of sources (point, area, stationary, etc.);

—the types of corresponding economic activity (industry, agriculture, service sector, etc.);

—combined categories of pollution (sulfur compounds, heavy metals, pesticides, easily decomposed organic compounds, hard-to-decompose organic compounds, etc.);

—individual pollutants (sulfur dioxide, mercury, insecticides, nitrogen etc.);

—levels of toxicity;
—basic spheres of diffusion (atmosphere, hydrosphere, soil, biota).

The connection with the system of intersectorial mass balance is achieved in the following manner. The total amount of the given pollutant, which is emitted during the given period of time in the given subregion, is calculated as the linear combination of the outputs of "clean" branches in this subregion, which in turn are calculated according to the model of the intersectorial mass balance [14].

The Spread of Pollution in the Atmosphere

This module establishes the quantitative connection between the sources of pollution and the field of precipitation.

Most works devoted to the study of the spread and fall-out of pollutants usually examine the transfer in a single direction under a selected synoptic situation with a scope of hours-days. Such an approach is justified when studying cases of the acute effect of atmospheric pollutants on the environment (especially on local scales). On regional scales the effect is most likely not acute but chronic, additive, and another approach is needed. This type of approach for regional scales is described, for example, in works [15,16].

Let us adopt the following symbols:

—$C(\bar{x}, t)$ is the amount of pollutant in the atmosphere per unit of area of the surface at point $\bar{x}=(x_1,x_2)$ at time t.
—T_{ls} is the life span of the pollutant in question in the atmosphere.

If the field of velocities of transfer $\bar{v}(\bar{x}, t)$ is known, then the dynamics of the magnitude $C(\bar{x}, t)$ will be described by the equation:

$$\frac{\delta C}{\delta t} + \mathrm{dir}(\bar{v}C) = -\frac{C}{T_{ls}} + Q(\bar{x}, t), \qquad (1)$$

where $Q(\bar{x}, t)$ is the intensity of the sources of pollution at time t.

The use of equation (1) is complicated, since there is often no information on the basis of which it would be possible to reproduce accurately enough the field $\bar{v}(\bar{x}, t)$. Therefore we used another, rougher model as well.

We will break the entire region down into sufficiently small areas, to which we attach the numbers $(i=1, 2, \ldots, N)$ and designate by P_{ij} the probability that the pollution in the area over the time Δ will be transferred to area j. If we designate by $C_i(t_k)$ the amount of pollution over area i at time t_k, we obtain the relationship:

$$e^{-\Delta/T_{ls}} \sum_i P_{ij} C_i(t_k) + Q_j(t_k)\Delta = C_j(t_{k+1}) \qquad (2)$$

$$\Delta = t_{k+1} - t_k, \qquad i, j = 1, 2, \ldots, N,$$

where $Q_j(t_k)$ is the intensity of the sources of pollution in area j and time t_k.

The field of precipitations is simply calculated according to the magnitude $C_i(t)$ by the formula:

$$\Omega_i(t) = C_i(t)/T_{ls} \qquad (3)$$

Successive integrations according to equations (2) and (3) give the dynamics of the field of precipitations.

The computation of the probabilities P_{ij}, which are needed in order to make the calculation, is carried out on the basis of the available information about the strength and recurrence of the direction of the winds:

$$P_{ij} = f(w_{ij}, r_{ij}/\Delta),$$

where $f(w_{ij}, r_{ij}/\Delta)$ is the recurrence of the winds in the direction w_{ij} (from area i to area j and with a force of r_{ij}/Δ), where r_{ij} is the distance between these areas.

The Transfer of Pollution from the Underlying Surface to Streams

Since the region is broken down into subregions, it can be thought that the run-off of pollution from the underlying land surface of each subregion occurs only into the corresponding stream. The dynamics of this process would be described in the following manner:

Let Z be the amount of pollution washed into the corresponding stream, then y and Z are interrelated by the equations:

$$\dot{Z} = C/T_{ls}S_{reg} - y \qquad (4)$$

$$\dot{y} = Z/T_{us} \qquad (5)$$

where C/T_{ls} is the intensity of the precipitation of the pollutant from the atmosphere; T_{us} is the time that the pollutant is in the underlying surface, which depends on the nature of the underlying surface and the amount of falling precipitation.

Equations (4) and (5) describe the dynamics of the pollution of the underlying surface during the autumn and summer seasons. During the winter and spring seasons the dynamics are different: there are no wash-offs in winter, i.e., $y=0$, while the pollution precipitated in winter and spring is washed off completely during the spring thaw.

We realize that the model (equations 4 and 5), which was described above, is very rough, but the selection of the model corresponds to the nature of the available information, since the processes being modeled here have been poorly studied.

The Carrying of Pollution by Streams

This module describes the dynamics of the flow of pollution into Lake Baykal, depending on the intensity of their entrance into streams and with due consideration for the processes of self-purification.

The equation is as follows:

$$\frac{\delta Q}{\delta t} = -\frac{\delta}{\delta x}(vQ) - \frac{Q}{T_{ls}^{w}} + A_{sew} + y, \tag{6}$$

where Q is the amount of pollution per unit of length of the stream; v is the velocity of the current; T_{ls}^{w} is the life span of the pollutant in the water, a constant that takes into consideration the action of various processes of self-purification; and A_{sew} is the intensity of the emission of sewage.

The intensity of the entrance of the pollutant into the lake can be calculated as follows:

$$q = Q_m / v_m,$$

where Q_m and v_m are the values of Q and v at the mouth of the stream.

Evaluation of the Zones of "Influence" of Major Sources and the Structure of the Fields of Pollution of Lake Baykal

On the basis of specially organized tracer experiments, which were conducted during the last few years, for determining the zones of the spread of man-made pollution in the region of Lake Baykal and for studying the balance of polluting substances, information was obtained which makes it possible to calculate the space-time picture of the actual zones of "influence" of the isolated sources and to obtain the fields of the concentrations of pollutants in Lake Baykal [17].

Prediction of the State of Natural Ecosystems

At the basis of the method of prediction we have placed the principle of the optimality of the specimen, which was first formulated by Rashevsky [18]. The history of the development of this concept goes back to Darwin. Without dwelling on this history of the question, let us cite the essential literature [19].

We use the mentioned principle of optimality in a somewhat modified form, since it is not practically possible to reveal and consider the ecological characteristics of an entire set of species. Therefore, for the sake of a constructive approach we single out in the ecosystem the "basic niches," and the systems of species occupying these "basic niches" are regarded as a "generalized species." Then from the principle of optimality, through the use of the biological principle of the interdependence of the characteristics of associations (the Matthew-Kermak principle), we obtain the system of relations, through whose resolution we find the parameters of the ecological system, depending on the man-made influences.

As an important additional instrument of the study of the ecological system most important to us — the ecosystem of Lake Baykal proper — we developed a mathematical simulation model of the pelagic zone of Lake Baykal, which is inhabited by the majority of endemic plants and animals and in which are produced the majority of products that play a determining role in the circulation of a substance and energy in the lake.

The model describes the dynamics of the main trophic levels of the ecosystem and is a system composed of ten ordinary differential equations. As an illustration, Figure 3, shows the DYNAMO-diagram of this model, while Table 1 gives the values of some of the parameters being used. The model was studied for stability through variation of the parameters within reasonable limits, and the obtained results were satisfactory: the model is sufficiently stable and can be used under real conditions, when the numerical values of some parameters are not well enough known. In the preliminary calculations the intensity of the man-made discharge, into Lake

TABLE 1. PARAMETERS OF THE MODEL OF THE ECOSYSTEM OF THE PELAGIC ZONE OF LAKE BAYKAL

Parameter	Numerical	Value
Coefficient of the expenditures on the exchange for zooplankton (epishura)	0.1	
Proportion of the assimilated food going toward the growth of the epishura	0.27	
Coefficient of the natural death rate of the epishura	0.037	1/day
Vant-Hoff coefficient for the calculation of the dependence of expenditure on the exchange for the epishura on air temperature	4.9	
Coefficient of the initial product (phytoplankton)	0.006 0.016	Spring Summer
Time for the decomposition of: dead phytoplankton dead zooplankton	 5 days 110 days	
Content of biogenes (N and P) and phyto- and zooplankton	10.3% 1.8%	For epishura
Optimum temperature limits for phytoplankton	1°C 15°C	Spring Summer
Intensity of anthropogenic sources of organic substances, biogenic elements and other "pollution"	Parameters fluctuate within broad limits	

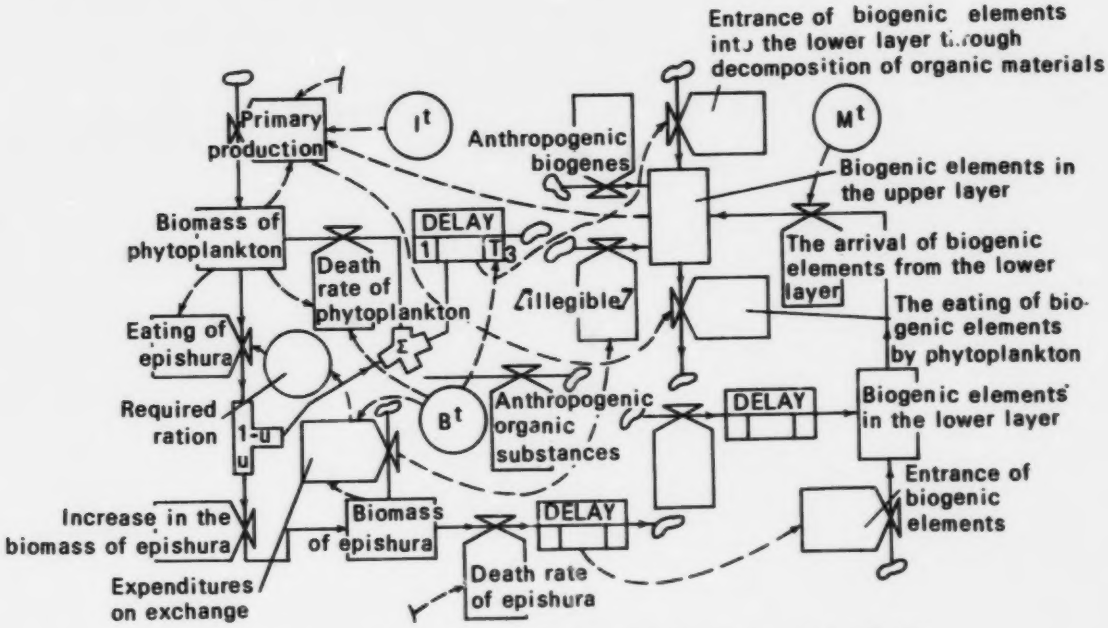
Entrance of biogenic elements into the lower layer through decomposition of organic materials
Primary production
I^t
Anthropogenic biogenes
M^t
Biogenic elements in the upper layer
Biomass of phytoplankton
DELAY
1
T
3
Death rate of phytoplankton
[illegible]
The arrival of biogenic elements from the lower layer
The eating of biogenic elements by phytoplankton
Eating of epishura
Σ
Required ration
1-u
u
B^t
Anthropogenic organic substances
DELAY
Biogenic elements in the lower layer
Entrance of biogenic elements
Increase in the biomass of epishura
Biomass of epishura
DELAY
Death rate of epishura
Expenditures on exchange

Figure 3. Dynamo-diagram of the model of the pelagic zone of Lake Baykal.

Baykal, of organic substances and biogenic elements fluctuated within broad limits. We assume that this study is of independent interest for the prevention of the eutrophication of bodies of water (for Lake Baykal this problem does not yet exist, yet its study makes sense).

Thus we are solving the task of predicting the state of the ecosystems under some external influence, in particular, under the influence of pollutants. In this direction the first encouraging results have already been obtained [14].

Evaluation of the Damage from Pollution and Optimization of the Use of the Natural Resources of the Region

Work [3] examined the scheme and described the types of possible damage from environmental pollution. The remarks cited below concretize this scheme.

When determining the optimum policy of exploitation of resources we should maximize a certain "global" function of the utility of the region given the limitations imposed by the levels of influences that are critical for the ecosystems.

Without examining the economic indicators of the exploitation of natural resources (this work is being conducted by Soviet economists [20]), we will consider as known the function of economic utility $C_0(S)$, where S is the vector of the regional economic policy.

Furthermore, we should determine the ecological damage to the ecosystems, which is caused by this policy S. Let us examine in more detail the types of damage.

For determining the damage to fishing, of decisive importance is the prediction in time, given this economic policy S, of the physical and chemical parameters of the abiotic sphere W (S, t). The utility connected with fishing (let us designate it as C_1) can be determined through a procedure such as the recognition of the types on the basis of the compilation of the actual data on the abiotic and industry indicators of similar bodies of waters. Such a procedure was proposed, in particular, in work [21]. From the formal point of view such a procedure is reminiscent of the compilation of a picture from the parts into which it was cut beforehand. At the basis of this procedure is the idea of the orderliness of the biota in the space of the components of the ecosystem in the form of some hyper-surface, to each point of which may correspond a set of the values of the parameters of the abiotic sphere.

The evaluation of the damage from pollution of water, which is regarded as an industrial resource, is not an ecological problem. The appropriate methods are available and are undergoing intensive development. We will not dwell on this in detail. Let us note only that we should take the set regional value of water at place g as a function of quality, which in turn is a function of the economic policy

S and time, and we should also use the prediction of industrial consumption V(t, S). Then the function connected with the utility of the water of the region will be represented in the form:

$$C_2 = g(t, S)V(t, S) + q$$

where q is the utility arising during exploitation.

The recreational damage in the case of Lake Baykal plays a very important role. In order to calculate the latter, let us designate, by $R_1(t, S)$, the recreational use of the lake in man-hours with due consideration for the time for coming to the lake, and, by r(t), the average wage rate. Furthermore, let $R_2(t, S)$ be the expenditure of the tourists. Then the utility as a result of recreational use, given the economic policy S, can be represented by the function:

$$C_3 = ar(t)R_1(t, S) + \frac{a}{2}R_2(t, S),$$

where the coefficient a expresses some permanent utility of the use of time of capital, which is characteristic for the state in general as an economic unit.

The economic evaluation of the ecological effects of diminishing of the variety of present species, in our opinion, is the most difficult problem, which must be resolved when converting to the rational management of natural resources. In order to solve this problem there must be intensive international cooperation. To us the following approach seems promising. It is necessary to construct predictions of the economic use of types within the major systematic categories in the next century. Then it is necessary to create as realistic as possible a model of technological evolution according to the main trends, which includes as parameters the number of types according to categories. After reducing the indicators of technological evolution to monetary units it is possible to proceed to an evaluation of the functions of the value of the abstract units of the variety of present species within the separate categories. We will designate by C_4 the value of the ecosystem of the region, which is connected with the composition of the variety of present species.

Finally, the optimum policy of the exploitation of the regional resources in time can be found as the optimum control of the functional of the global utility of the region, which is represented in the form:

$$\int_0^\infty e^{-bt}(C_0 + C_1 + C_2 + C_3 + C_4)dt,$$

where e^{-bt} is a discount factor.

In conclusion, let us note once again that the reality of this approach to the optimization of the management of natural resources depends largely on the success in the economic evaluation of the utility of the fund of present species, since the meaning of the remaining components of the functional of the global utility of the region is quite clear and the possibility of making specific calculations of the corresponding values is not in doubt.

As an example, let us cite our evaluations of the influence of pollution when combatting chemically massive conifer and leaf mining pests of the forests of the Lake Baykal region. At present DDT is not produced in the USSR and is not used in forestry. We made evaluations of the use of DDT only for purely methodological purposes, since this insecticide has been well studied.

For evaluating the positive economic effects of the campaign, a sufficiently detailed model has been proposed [22]. In calculating the undesirable side effects of chemical control we take into consideration the following circumstances [14]:

—The probability of an unsuccessful campaign.

—A breakdown in the stability of the forest ecosystem (an increase in the duration of rapid rises in the number of pests and a decrease in the period between the rapid rises).

—The loss to livestock breeding and agriculture.

—Recreational damage.

The model obtained was used to determine the feasibility of chemical control of the pests of the forests of the Lake Baykal region. For typical conditions we obtained a negative response.* Apparently this method can be considered acceptable.

EXAMPLES OF POSSIBLE USE OF THE MODEL

Although, as was noted, we do not at present consider the described model entirely complete (the model has only gone through the test stage), as an illustration we will describe examples of its possible application.

The use of individual modules is of definite independent interest.

Thus, the preceding modules (the carrying of pollution by different geophysical mediums) make it possible within the complex to evaluate the scope of pollution of the natural environment and, in particular, to obtain an answer to such a practically important question: what is the relative significance of the various sources of pollution in respect to their influence on the ecological system of Lake Baykal (and the other ecosystems of the region)? Preliminary calculations show that the Selenga River (the area of whose catchment is 60% of the total area of the lake basin and whose flow is 50% of the total flow of all rivers into Lake Baykal) has a very great capacity for "self-purification"; on the sector from the city of Ulan-Ude to the mouth this capacity for "self-purification" with respect to various ingredients of pollution and to indicators of water quality varies from 10^3 to 10^4. Thus, the Baykal'sk Pulp and Paper Mill, with all other conditions being equal, being located in the region of Ulan-Ude, would have an influence on the Lake Baykal ecosystem that is 10^3 to 10^4 times less.

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*At present biological means of combatting forest pests are being used on an increasingly extensive basis in the Lake Baykal region.

On the other hand, the calculations show that the presently existing distribution of the sources of pollution and of the influence on the ecosystem of the lake gives rise to a new role for Selenga River in the undesirable accumulation in the lake of organic substances of allochthonous origin. These calculations, in general, agree with the available data of observations.

Finally, the calculations using these modules show the great possible significance for the hydrochemistry of the lake and the state of its ecosystem of the distant atmospheric transfer of pollution.

The modules (prediction of the state of natural ecosystems and evaluation of the damage from pollution and the optimization of the use of the natural resources of the region) even in their present incomplete form can be used for a rough prediction of the state of some basic ecosystems and for a preliminary calculation of the permissible loads of pollution.

Of no little importance is the following circumstance. Each of the described modules, being a part of the total model, should be "balanced" with all the other modules in the sense that the precision and detail of the results they produce should be approximately identical (it is extremely uneconomical and, in general, senseless to be endlessly occupied with refining the models of transfer and at the same time to leave in the background the inventory of sources or the evaluation of the damage caused by pollution). This general systems assertion is of great practical significance and, as we have already noted in the General Description of the Model, has made it possible for us to refine the program of further research on the region.

Use of the model as a whole is of very great interest, since it makes it possible to conduct a comprehensive, thorough analysis of the influence of national economic activity on environmental quality and the functioning of the ecological systems of the Lake Baykal region. The model has a prognostic capacity, and it can be used for examining and evaluating (from the point of view of the influence on the environment) various alternative variants of the development of the national economy in the region.

In short, the problem of evaluating the influence of national economic activity consists in *distinguishing* the man-made changes of the environment and in their *comprehension* in some proper, more extensive concepts outside the model — metaterms (the well-being or troubles of the predictable state of the natural environment, in connection with this the desirability or undesirability of carrying out a proposed project or action).

More strictly speaking, we can place this problem in the following form.

It is necessary:

- —to describe the suggested *influence* and all its alternatives,
- —to predict the nature and scope of the result of the influence,
- —to formulate the criteria of environmental protection in this specific case,
- —to compile a list of usable *indicators*, of which there may be very many, and to formulate a rule of "summation" of these indicators with the purpose of facilitating the decision-making of the appropriate units of government,
- —to make one of the following recommendations:
  - —to adopt the proposed project of economic development,
  - —to undertake the necessary measures to alter the project and protect the environment,
  - —to adopt an alternative project,
  - —to reject the proposed project,
- —to make recommendations on measures to monitor the environmental quality after completion of the project (if it is adopted).

Of course, we should not adopt too punctually the formulated form of the question. It often happens that the complete implementation of all the steps of this problem of evaluating the influence on the environment is complicated owing to the complexity of the problems and the existence of many uncertainties. At first there may be rearrangements of the order of the individual steps or their combination. The formulated form of the problem should be taken as a "guide to action" and later its reformulation is possible.

We see the following possible scheme of the application of our model within the framework of this program. Within the module (the evaluation of the damage caused by pollution and the optimization of the use of the natural resources of the region) there is at first an evaluation of the permissible (from the ecological standpoint) loads of pollution. Within the expanded system of the intersectorial mass balance (to which clearly belong the various types of emissions and pollution, as well as their corresponding "sectors" of refinement or utilization of emissions and pollution) the "optimal" national economic program is determined. Such a program will ensure the volume and structure of the finished product, which are set by planning units. At the same time the volume of pollution emitted into the environment corresponds to some "norm," which is determined by the above-evaluated magnitude of the permissible load on the environment.

Thus, the model makes it possible to examine and evaluate different (including technological) methods of combatting pollution. In principle the described approach may also be useful for other regions.

SUMMARY

The proposed mass-balance simulation model of the Lake Baykal region is in practice an applicable instrument of the comprehensive analysis, long-range prediction and determination of the permissible loads of the influence of national economic activity on environmental quality and the functioning of natural ecological systems. Even at this early stage, when not all of the modules have been developed to the same degree, this model has made it possible to obtain practical, interesting results. For the least developed modules — the prediction of the state of natural ecosystems and the evaluation of the damage caused by pollution and the optimization of the use of the natural resources of the region — the paths of improving and finishing them are suggested.

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MANAGEMENT SYSTEMS FOR MINIMIZING REGIONAL ENVIRONMENTAL STRESS: RESEARCH ON APPLIED ASPECTS OF PLANNING, IMPLEMENTATION AND ENFORCEMENT

CHARLES N. EHLER

The determination of the health and ecological effects of various pollutants and the establishment of maximum permissible environmental loadings (for example, the establishment of ambient air or water quality standards) is only one, albeit very important, set of decisions that makes up a management system that will ensure the achievement and maintenance of specified levels of ambient environmental quality in any given region. The purpose of this paper is to lay out the components of such a management system and to review briefly the results of research to date on the development of such systems for implementation at the non-Federal (that is, regional) level of government in the United States.

Before beginning, I would like to narrow the discussion by defining what I mean by the term, "environmental quality," since in practice it appears to have as many definitions as there are individuals defining it. For example, to the public health official, environmental quality involves vector control, food sanitation, and so on. To the architect or urban planner, environmental quality means the visual or aesthetic quality of buildings arranged in space. To the ecologist, environmental quality might mean preserving the integrity of the natural ecosystem. And so on. It is notoriously a term which is universally difficult to get politicians, bureaucrats, scientists, or the general public to agree on what it is —or how to measure it.

In the United States, the Environmental Protection Agency is primarily interested in regulating one very important subset of environmental quality problems — those that relate to the discharge of society's leftovers from production and consumption into one or more of the natural environmental media — air, land or water. This sector of problems has been termed the *residuals-environmental quality sector*. It is the management of this sector of problems that I will now turn to.

Residuals are the non-product (either material or energy) outputs of production, the value of which is less than the costs of collecting, processing and transporting it for use. Thus, the definition is time-dependent, i.e., is a function of the level of technology in the society at the point in time and of the relative costs of alternative inputs to production. For example, manure in the United States is now a residual, whereas 30 years ago it was a valuable raw material.

Two basic types of residuals exist — material and energy. The former has three major forms — liquid, solid and gaseous. Examples of liquid, or water-borne, residuals would include suspended solids and phosphorus; gaseous, or air-borne, residuals would include carbon monoxide, hydrocarbons, and sulfur oxides; solid, or land-borne, residuals would include wastepaper, yard wastes, junk automobiles, and so on. The major energy residuals are heat, noise, and in a simplified sense, radiation.

Residuals are pervasive. No production process has yet been designed to completely convert all material and energy inputs to product outputs. All activities of society result in the generation and discharge of some material and energy residuals. The weight of residuals discharged into the air, water, or land, is approximately equal to the weight of the raw materials entering various production processes less the weight of the product output (consumer goods) produced. This materials balance equation simply states that the mass of materials used by society remains in existence over time in some gaseous, liquid, solid or energy form, eventually to be discharged into the natural environment.

It is important to emphasize the inter-relationships among the three forms of material residuals — one form of material can be transformed into another and additional material and energy residuals are often produced in modifying a particular residual. Further, material residuals can be traded off for energy residuals.

These inter-relationships can be simply illustrated by considering a power plant using coal as the fuel for electric energy generation. The particulates formed in combustion can be discharged to the atmosphere in the gaseous stream, that is, up the stack as a gaseous residual. If, however, there are environmental constraints on such discharges, a wet scrubber could be installed to wash the particulates out of the gas stream, thereby transforming the gaseous residual into a liquid residual, that is, suspended solids, which could then be discharged to an adjacent river. Such discharge might adversely affect water quality, with consequent damage to fish. To prevent such an impact, a settling basin could be installed to settle out the suspended solids in the liquid residual, thereby yielding a solid residual for disposal on the land.

EPA promulgated (April 1971) primary and secondary standards for hydrocarbons, carbon monoxide, nitrogen dioxide, sulfur oxides and particulate matter—all airborne residuals. In addition, standards have also been set for photochemical oxidants, even though they are not directly emitted to the air, but are a product of atmospheric reactions between nitrogen oxides and reactive hydrocarbons. National primary ambient air quality standards are specified at a level of air quality requisite to protect the public health, and national secondary ambient air quality standards are specified at a level of air quality requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of air pollutant in the ambient air.

Ambient water quality standards are called for under Section 303 (c) (2) of the Federal Water Pollution Control Act which states that, "whenever the State revises or adopts a new standard, . . .such revised or new water quality standard shall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses. Such standards shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act. Such standards shall be established taking into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and also taking into consideration their use and value for navigation." The purposes of the Act are defined in Section 101 and include "an interim goal of (ambient) water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water to be achieved by July 1, 1983." At present no criteria or standards exist for determining "ambient land quality." EPA does, however, issue guidelines for sanitary landfills and other solid residuals disposal activities.

With these standards and guidelines as planning objectives that will satisfy legislated environmental quality goals, let's look in more detail at the planning and management activities that EPA is requiring State, regional and local governments to undertake in response to Federal legislation — specifically Air Quality Maintenance and Areawide Waste Treatment Management planning guidelines.

After the Federal air quality standards were established, the States were required to submit plans by which they would ensure that the standards would be attained by 1975. The States hurriedly responded to this requirement and on May 31, 1972, EPA published its approvals and disapprovals of the State Implementation Plans, and a little later, promulgated substitute regulations for deficient State plans.

However, not everyone was satisfied that the plan approvals were justified. Section 110 of the Clean Air Act specifies the conditions under which a State Implementation Plan may be approved. One of the conditions states that the plan must include ". . . emission limitations, schedules, and timetables for compliance with such limitations, and such other measures as may be necessary to ensure attainment and *maintenance* of such primary or secondary standards, including, but not limited to, land use and transportation controls. . . ." The Natural Resources Defense Council (NRDC) challenged EPA's approvals on the basis of this passage. NRDC contended that while the plans may have been adequate to insure attainment of the standards by 1975, they were *not* adequate to insure maintenance of the standards beyond 1975. On January 31, 1973, the U. S. Court of Appeals for the District of Columbia ordered EPA to once again review all State Implementation Plans to determine if they did contain adequate measures to insure maintenance of standards. EPA did so, found all plans inadequate, and disapproved them with respect to maintenance on March 8, 1973. Then, on June 18, 1973, EPA promulgated regulations requiring States to develop Air Quality Maintenance Plans for areas with the potential for exceeding a National Ambient Air Quality Standard between 1975 and 1985.

From June 1973 until very recently, EPA and the States have been mainly involved with designating these air quality maintenance areas. They have now reached the point where the in-depth analysis and plan development for these areas must begin.

To date, EPA has identified a total of 102 Air Quality Maintenance Areas and is preparing notices to identify approximately 60 other areas.

The Federal Water Pollution Control Act Amendments of 1972 set forth requirements for controlling all types of water pollution. Section 208 of the Act provides for Areawide Waste Treatment Management Planning in areas with substantial water quality control problems due to urban-industrial concentrations or other factors. Regulations on 208 area and agency designations were published by EPA in September 1973.

Through Section 208 planning, local areas are provided a unique opportunity to plan and manage a comprehensive pollution control program for municipal and industrial wastewater, storm and combined sewer runoff, non-point source control and land use, as it relates to water quality. Through a locally controlled planning agency, an area can select a cost-effective and institutionally feasible plan directed toward meeting the 1983 goals of the Federal Water Pollution Control Act. It will focus on an integrated approach for identifying and controlling the most serious water pollution problems initially and, over time, resolving the remaining problems, where feasible. Particular emphasis will be placed upon non-structural approaches to pollution control, such as fiscal policy and land management, rather than traditional structural measures normally requiring large capital investments. The management agency and institutional arrangements most able to insure implementation of the plan would also be selected by the area. Periodic review and updating of the plan and management arrangements will allow for response to new information and changing conditions.

To date, approximately 149 areas have been designated as 208 planning areas, but it is anticipated that most metropolitan areas, roughly 250, will be preparing 208 plans. Additionally, all 50 States, will be preparing plans for non-designated areas of their respective States.

Many metropolitan regions of the United States will require the preparation of both Air Quality Maintenance and 208-type plans.

Having defined the planning objectives as attaining and maintaining Federally and State-specified levels of ambient air and water quality, and having briefly outlined the planning and management requirements for regional waste management planning, let's now turn to examining the kinds of information needed by non-Federal environmental planners and managers in order to develop strategies for accomplishing these objectives.

First, we should identify and describe the "system" that we are attempting to plan and manage. What are the economic and physical (or technological) components of the residuals-environmental quality management system? Stated another way, what are the variables that in combination determine ambient environmental quality?

In any given region, activities are distributed over space and time. This spatial and temporal pattern both reflects and affects "final demand," that is, the total goods and services desired by society. Each of the individual activities — households, industrial plants, transportation systems, and so on — reflects (1) some combination of factor inputs to produce a given output or service, or, as in the case of households, to use the products and services; and (2) the generation of various types and quantities of residuals. The activities can be characterized as point (for example, an industrial plant), line (for example, traffic flow on a major artery), or area or non-point (for example, agricultural operations or residential areas) sources of residuals.

In the environment, residuals undergo various physical, chemical, and biological processes — transport, decomposition, sedimentation, accumulation, and so on. These processes transform the time and spatial pattern of residuals discharge from the various activities into a resulting time and spatial pattern of ambient environmental quality, measured by whatever indicators are of interest, for example, concentration of sulfur dioxide in the atmosphere, concentration of suspended solids in river water, hectares of land disturbed by strip mining, and so on.

The resulting ambient environmental quality impinges directly on the receptors — humans, plants, animals, materials. The impacts on the receptors, that is, "damages," as perceived by human beings, and the responses of individuals and groups to the perceived damages, provide the stimulus for action. Figure 1 is a simple representation of these relationships.

But in fact we are dealing with a very complicated technological, economic and social system. Ambient environmental quality is determined by a

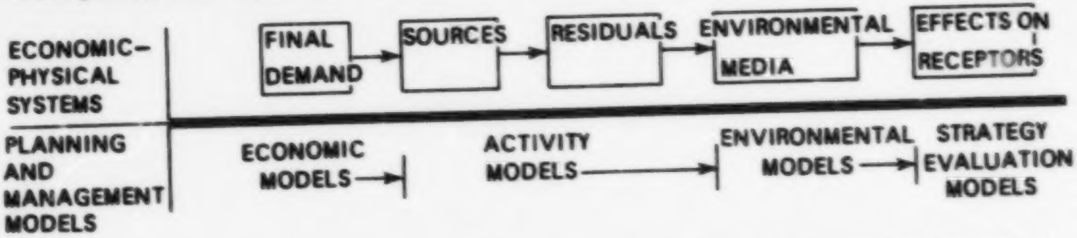

Figure 1. Relationships of residuals-environmental quality management models to economic/physical systems.

number of regional variables including the "final demand" for goods and services desired by society (for example, the number of BTU's required per household for space heating, the number of passenger trips per person for work purposes, and so on), the spatial and temporal distribution of activities (that is, the land use patterns) in any given region (for example, the spatial pattern of activities determines the type of regional transportation system), regional production technologies (for example, the nature of industrial unit production processes, or the type of transportation system — internal combustion engine automobile, electrically powered mass transportation, etc.), the raw material and energy inputs to production processes (for example, the sulfur content of fuels used), the nature of technology used for material and energy recovery, for by-product production, for "waste treatment," and so on, as well as technologies for directly modifying the assimilative capacity of the natural environment. The functional relationships of these variables are illustrated in Figure 2.

Action to perceptions of environmental quality problems is reflected in the development of residuals management strategies through a continuing management process, consisting of the components illustrated in Figure 3. The development of residuals management strategies should involve the identification and evaluation of the complete range of: (1)*physical methods* or technological options with which to affect residuals generation and discharge or to modify the assimilative capacity of the natural environment directly, see Table 1; (2) the identification of related *implementation measures* with which to affect the physical methods, see Table 2; and (3) *institutional arrangements* that have the authority to affect the implementation measures and incentives. Through the identification of a complete range of residuals management components, decisionmakers can be made aware of the variety of alternative means for achieving environmental quality objectives in an economical, efficient and equitable manner. This stage of the management process should be undertaken without consideration of constraints, such as the level of technology currently available, legal authority to implement, potential economic impacts, political feasibility, and so on. Constraints are not to be disregarded, of course, but they are more constructively considered in the later evaluation and selection phases of the management process.

TABLE 1. PHYSICAL METHODS (OR TECHNOLOGICAL OPTIONS)

A. METHODS TO REDUCE/MODIFY "FINAL DEMAND" FOR GOODS AND SERVICES
  Examples: reduce per capita use of goods and services, limit absolute population in given area, change "life-style," etc.

B. METHODS FOR REDUCING THE DISCHARGE OF WASTES (RESIDUALS)
1. Methods for reducing residuals generation
    a. Change inputs to production processes
        1. raw materials (including water)
        2. energy
    b. Change production processes
        1. process technology
        2. operating rate
    c. Change mix of product outputs
    d. Change individual product output specifications
2. Methods for modifying residuals after generation
    a. Apply materials or energy recovery technology (direct recycle)
    b. Utilize by-products of production (indirect recycle)
        1. on-site
        2. joint or collective facility
    c. Apply waste treatment (pollution control) technology (without recovery of any material or energy)
        1. on-site
        2. joint or collective facility

C. METHODS DIRECTLY INVOLVING THE ASSIMILATIVE CAPACITY OF THE NATURAL ENVIRONMENT (AIR, WATER, LAND)
1. Methods for making better use of the existing assimilative capacity of the natural environment
    a. Change the spatial distribution of existing or new activities
    b. Change the temporal distribution of existing or new activities
    c. Change the spatial distribution of the discharge of residuals
    d. Change the temporal distribution of the discharge of residuals
2. Methods for increasing the assimilative capacity of the natural environment
    Examples: low flow augmentation, artificial mixing, artificial aeration, weather modification, etc.

D. FINAL PROTECTIVE METHODS
  Examples: air conditioning, sound-proofing, thermal insulation, etc.

After the alternative residuals management strategies are identified and evaluated (see Table 3 for a suggested set of evaluation criteria), and the "best" strategy has been identified, based upon the "weights" given to each of the evaluation criteria, the strategy is implemented. Implementation would include the construction of facilities, the collection of effluent charges, and so on. Implementation, in turn, is followed by enforcement, monitoring and surveillance.

The strategy as implemented is then subject to ongoing evaluation with continuing feedback so that the decision-makers can make the predictably necessary adjustments to the strategy. The entire management process is a repetitive one with continuous feedback and recognition of the interrelation of each step.

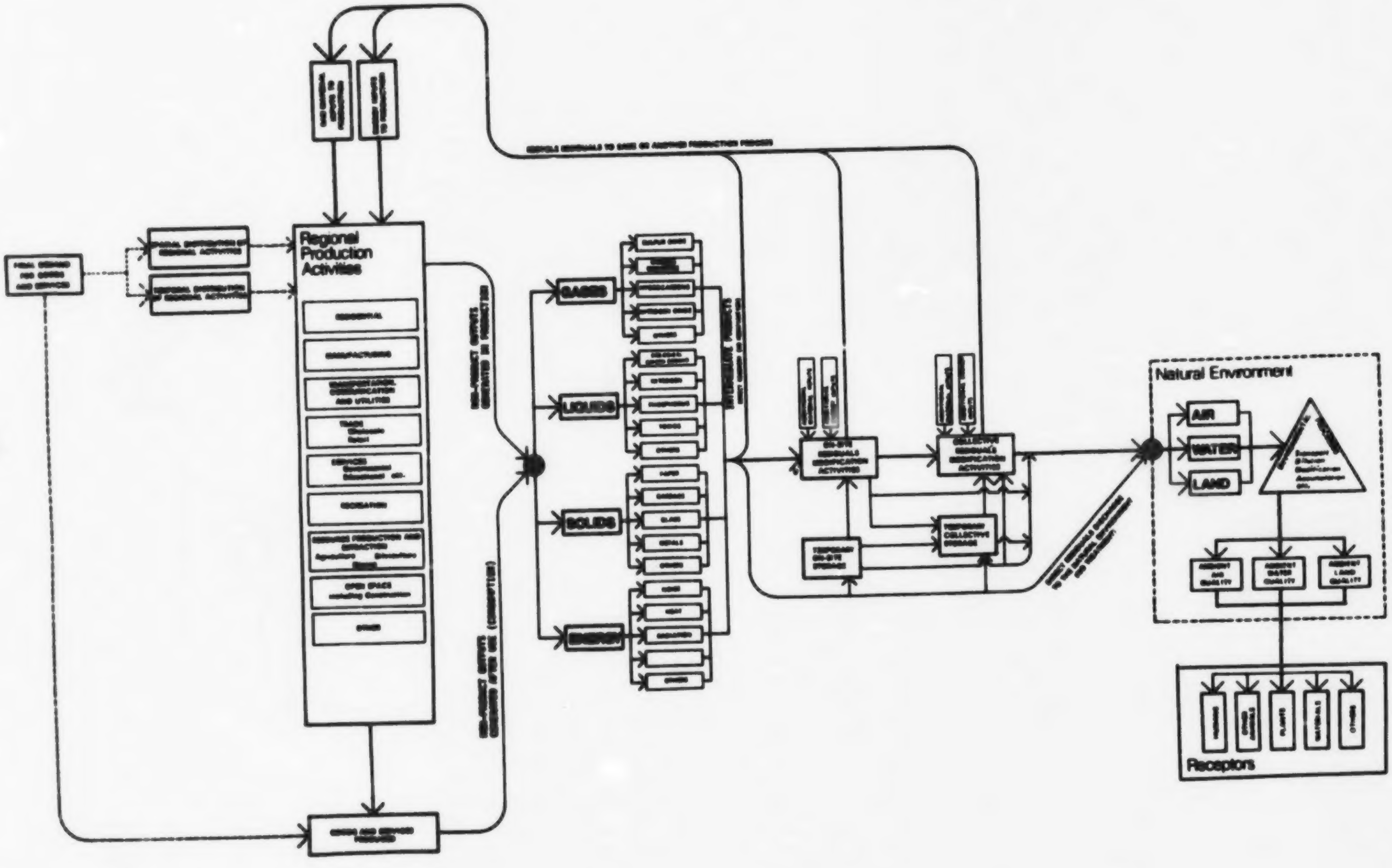
Regional Production Activities
GASES
LIQUIDS
SOLIDS
ENERGY
ON-SITE RESIDUALS MODIFICATION ACTIVITIES
COLLECTIVE RESIDUALS MODIFICATION ACTIVITIES
TEMPORARY ON-SITE STORAGE
TEMPORARY COLLECTIVE STORAGE
Natural Environment
AIR
WATER
LAND
Receptors

Figure 2. Regional residuals-environmental quality system.

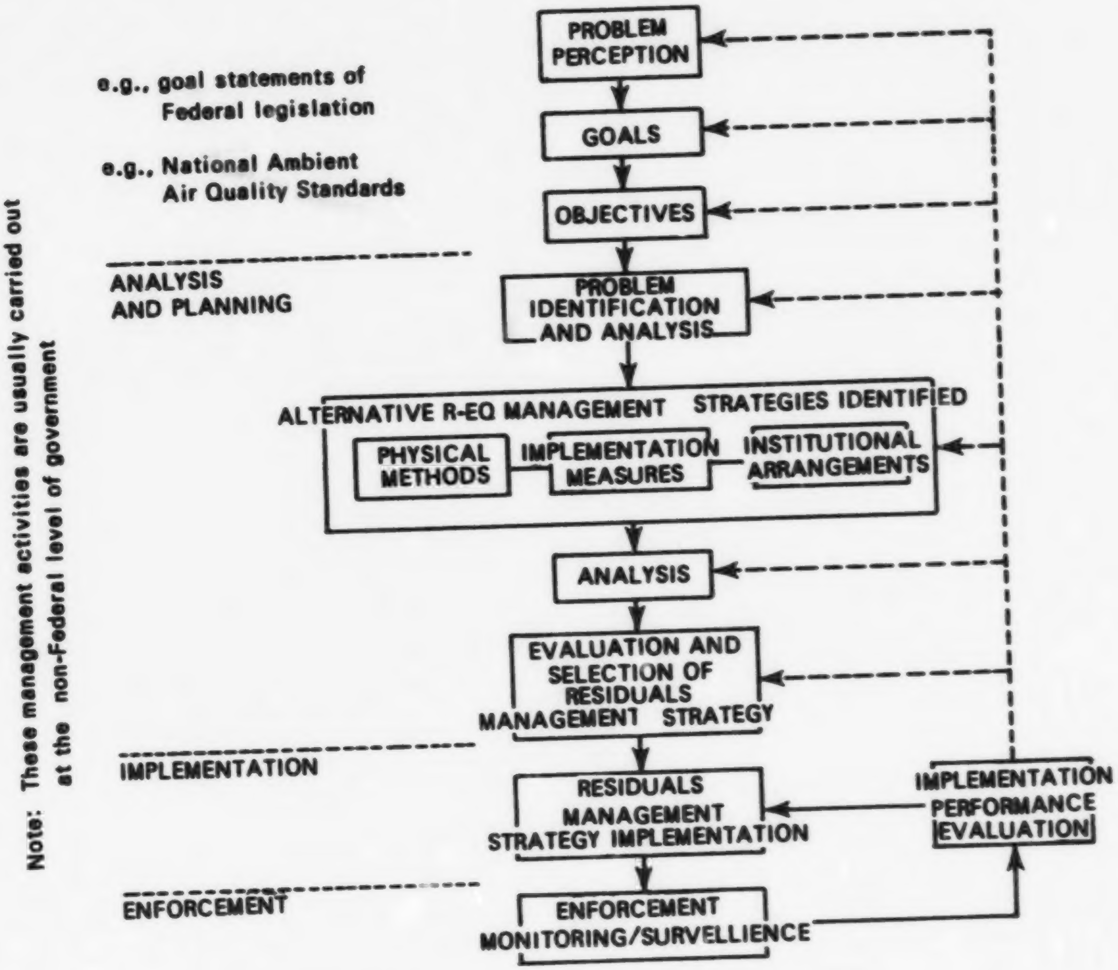
PROBLEM PERCEPTION
e.g., goal statements of Federal legislation
GOALS
e.g., National Ambient Air Quality Standards
OBJECTIVES
ANALYSIS AND PLANNING
PROBLEM IDENTIFICATION AND ANALYSIS
ALTERNATIVE R-EQ MANAGEMENT STRATEGIES IDENTIFIED
PHYSICAL METHODS
IMPLEMENTATION MEASURES
INSTITUTIONAL ARRANGEMENTS
ANALYSIS
EVALUATION AND SELECTION OF RESIDUALS MANAGEMENT STRATEGY
IMPLEMENTATION
RESIDUALS MANAGEMENT STRATEGY IMPLEMENTATION
IMPLEMENTATION PERFORMANCE EVALUATION
ENFORCEMENT
ENFORCEMENT MONITORING/SURVELLIENCE
Note: These management activities are usually carried out at the non-Federal level of government

Figure 3. Residuals-environmental quality management process.

To reiterate then, an environmental quality management strategy is a specified set of physical methods, implementation measures, and institutional arrangements to be carried out over space and time to achieve some change in ambient environmental quality. Physical methods are specified actions which result in a change in the quantity, type, timing, or spatial location of residuals discharged into the ambient environment. Examples of such changes would include: changes in raw material inputs, changes in production processes, materials or energy recovery, changes in the time scheduling of activities, changes in the spatial location of activities, modification of topographical conditions, and so on. (Note: The "valves" on Figure 4 are coded to Table 1, illustrating possible points of management intervention *in the economic-physical* system that generates and discharges residuals).

Specified physical methods are affected through a related set of implementation measures. For any given physical method, there are often several measures available for implementation. Implementation measures include: economic incentives, subsidies, residuals charges, standard setting, zoning, capital improvements programming, performance or product specifications, and so on. For example, a change in the raw material input (fuel) to a power plant (a specified physical method) could be achieved by writing and enforcing a specification (an implementation measure) on the sulfur content of the fuel used in energy conversion. Similarly, a change in the spatial location of activities (a physical method) can be achieved through zoning, capital improvements, tax policy, or a combination of these instruments.

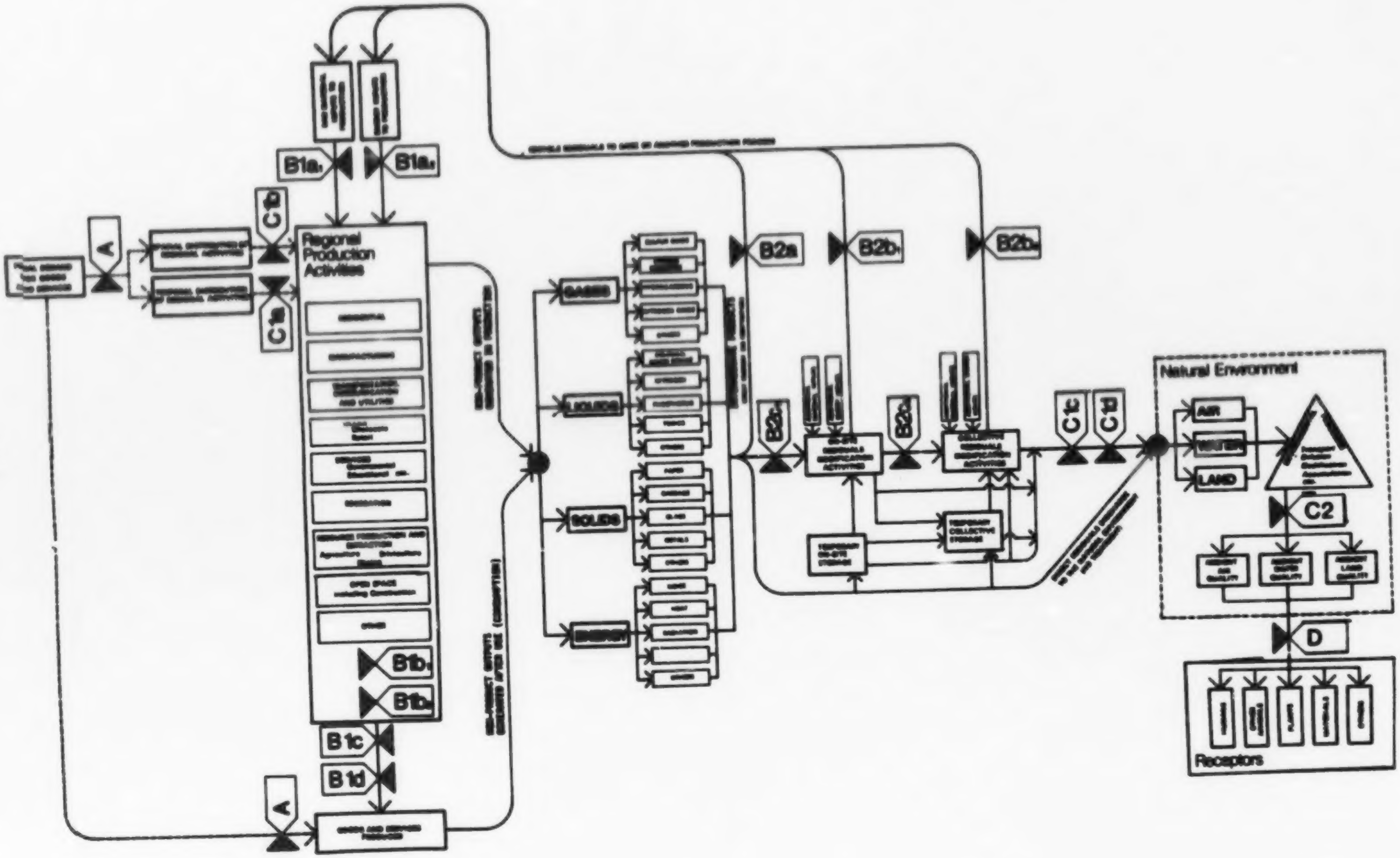
Regional Production Activities
A
C1b
C1a
B1a1
B1a2
B1b1
B1b2
B1c
B1d
A
GASES
LIQUIDS
SOLIDS
ENERGY
B2a
B2b1
B2b2
B2c1
B2c2
C1c
C1d
Natural Environment
AIR
WATER
LAND
C2
D
Receptors

Figure 4. Regional residuals-environmental quality management interventions.

TABLE 2. IMPLEMENTATION MEASURES/ INCENTIVES

A. REGULATORY
  1. Specifications of physical method
    a. Specify raw material or energy input standards
    b. Specify production process standard
    c. Specify product output standard
    d. Specify residuals modification or handling standard
  2. Specification of performance or result
    a. Specify residuals discharge standard
      1. per unit of product output
      2. per unit of raw material processes
      3. per unit of time
    b. Specify residuals concentration natural environment (ambient environmental standards)
    c. Specify technological performance standards
  3. Specification of location of activities (land use regulations)
  4. Specification of size, timing and type of activities
  5. Specification of regulatory procedures
     Examples: EIS requirements, procedural planning requirements, compliance schedule preparation, etc.

B. ECONOMIC
  1. Direct application to residuals
     Examples: effluent/emission charges, fines for spills, sale of discharge rights, etc.
  2. Application to raw material/energy inputs or product outputs
     Examples: surcharge on energy use, charge on each pound of DDT applied, etc.
  3. Applications to activities
     Examples: parking surcharges, subsidies for mass transit, differential property taxes, etc.
  4. Application to residuals modification or handling
     Examples: Federal grants for sewage treatment facilities, tax write-offs on costs of installation of treatment technologies, etc.
  5. Direct public investment in other than residuals modification or handling technologies
     Examples: open space land banking, mass transit investments, etc.

C. ADMINISTRATIVE (procedures and activities within public or private organizations that can be used to modify residuals generation and discharge)
   Examples: purchasing procedures, requiring separation of solid residuals for recycling, car pool requirements, specification of lighting levels within offices, etc.

D. EDUCATIONAL/INFORMATIONAL
   Examples: provision of technical information, forums/seminars/workshops, public relations, public interest group support, etc.

TABLE 3. POSSIBLE REQM STRATEGY EVALUATION CRITERIA

Physical effects:
—Reduction in quantities discharged to ambient environment.
—Improvements in ambient environmental quality.

Economic effects:
—Direct costs are expenditures required in responding to a particular strategy. These include investment and operating costs for control equipment, incremental costs of fuel switching, costs of production, process changes, emission monitoring costs, administrative costs for accounting and reporting, costs of supervision of operating personnel, and costs required of the governmental unit for implementing and enforcing a strategy, such as operating costs for permit review programs, monitoring air quality, review source inventories, and source surveillance.
—Other economic effects are the benefits and costs that accrue to society as a result of implementing a particular residuals management strategy. These may include employment, income to other firms, change in income tax, changes in property taxes, change to new receptors, increased cost of user goods and dislocation of people.

Legal consideration in terms of:
—Existing enabling legislation.
—Nature and extent of legal precedents.
—Susceptibility of implementation measure to legal challenge.
—New legislation required.

Administrative considerations in terms of flexibility; i.e., the strategy must be able to respond effectively to:
—Seasonal variations.
—Changes in prices, technology, etc. over time.
—New information—e.g., as the national system (ambient environment) responds the strategy must be able to adjust.
—New goals, new priorities—e.g., as society's needs and desires change, new people are elected or appointed to decision-making positions.

Time considerations—institutional arrangements must account for lapsed time from passage (adoption) of ordinance or regulation (implementation measure) to actual response by residuals generators in initiating their actions (selection of physical methods):
—Time required to implement strategy.
—Time required to obtain first results and/or benefits.

Political considerations in terms of feasibility of adoption.

Public responsiveness in terms of acceptability.

There is also the institutional dimension to formulating regional residuals-environmental quality management strategies. A number of questions arise. One is concerned with the legality of the use of various measures for environmental quality management by different levels of government. For example: Can the Federal government specify incinerator standards? Can a metropolitan government or municipality levy a residuals charge on discharges? Can the Federal government prevent the use of certain kinds of raw materials in production processes, or prevent by legislation the production of goods which are either non-degradable or non-returnable? Which levels of government can impose regulations affecting industrial location, or the spatial pattern of economic activities in general, with a view to improving environmental quality? Which management mechanisms will "get the job done" most effectively? Most efficiently? Most equitably?

Obviously a wide range of physical methods, implementation measures, and institutional arrangements exist for developing residuals management strategies with which to handle a wide range of environmental quality problems. To illustrate, a region that (a) depends mostly on electric space heating and electrically powered mass transit — the latter a function of transportation and land use policies, (b) utilizes efficient wet scrubbing of stack gases from industries and power plants, and (c) disposes of garbage by grinding, transporting in sewers, discharging it untreated to water courses, would have high air quality. But the water courses of the region would be subjected to a heavy residuals load, with probable severely adverse consequences on water quality. Alternatively, suppose the region treats its municipal and industrial liquid residuals to a high degree, and relies almost exclusively on incineration of sludges and solid residuals to handle the residuals from these treatment processes. High quality of the water and land environments would result, but at the expense of a heavy residuals load discharged to the air. If the region were to practice high-level recovery of residuals with the related recycling and by-product production, combined with the stimulation of production processes which resulted in the generation of small quantities of residuals per unit of product and service, very few residuals might well be discharged into any of the natural environments.

In order to analyze residuals-environmental quality management in any region, various relationships must be developed. These include not only estimates of residuals generation coefficients, and relationships between the time and spatial patterns of residuals discharged into the environment and resulting ambient environmental quality, but also relationships between environmental quality and damages to various users, and relationships between the costs of residuals modifications or reduction and the degree of reduction. For example, the cost of particulate removal from a gaseous stream increases as the degree of removal increases. As 100% removal is approached, the incremental cost increases very rapidly. At the same time, there are economies of scale in residuals handling, modification, and disposal.

Ambient environmental quality varies both in time and in space. Environmental quality is stochastic in nature because of the time variation of assimilative capacity and the time variation in the generation and discharge of residuals. Thus, the analysis of residuals-environmental quality and policies for residuals management must include explicit consideration of space. For example, recent studies have shown that failure to consider the locations of liquid residuals discharges can increase costs by 50% or more, to achieve a desired level of quality, if all dischargers are required to reduce by the same amounts regardless of their impacts on water quality. Failure to consider the locations of gaseous residuals discharges and the affected receptors in an airshed — in relation to variation in assimilative capacity over the airshed — can double the costs to achieve a given level of air quality. In a recent study, jointly funded by the Council on Environmental Quality, the Department of Housing and the U. S. Environmental Protection Agency, it was calculated that planned low-density residential development in clusters can reduce air pollution by 20 to 30% and energy consumption by about 14%. Planned higher density development can further reduce these effects. With higher density development, air pollution can be reduced by as much as 45%. Both good planning and the use of higher density development can lead to reductions in water pollution as well.

The feasibility, costs and effectiveness of residuals-environmental quality management strategies are heavily dependent upon policies relating to land use and regional development, that is, the timing and location of activities in a metropolitan region. For example, transportation oriented toward mass transit will rarely be feasible except where the regional pattern consists of a core city or, at minimum, concentrated subcenters of activity. Similarly, heating of dwelling units from communal rather than individual systems is not feasible with a dispersed settlement pattern. The costs of many of the residuals recovery-recycling systems, increase rapidly with urban sprawl.

A major challenge then to regional planners and decision-makers is to incorporate the problems of residuals-environmental quality management explicitly into their plans and operating decisions. This integration of environmental considerations into regional land use decisions is key to the future success of environmental programs. This is precisely the kind of consideration that EPA hopes to have built into the regional planning and management process through its current planning requirements.

In conclusion, this paper has explored the nature of the residuals problem, described the elements of residuals-environmental quality management strategies, and developed an overall management process. These concepts and principles are being further developed in research projects of the Regional Environmental Management Program in the Office of Research and Development. A list of current extra-mural research is appended to this paper.

One final comment — in no situation in which the residuals-environmental quality management framework is to be applied to a given region will there be unlimited time, resources and data. A decision concerning selection of an REQM strategy to be applied in a given area may have to be made in one month, one year, or occasionally only after several years. What is important to be emphasized is that the approach is the same, regardless of the amount of time and resources available. The methodology can be applied within whatever time and resource constraints exist. The difference is in the degree of detail applied to the various elements of the analysis and strategy development. For example, with fewer resources, fewer models of residuals generation and discharge from various activities will be developed — more aggregate models will be necessary; fewer and less detailed, and probably less accurate environmental models and less accurate cost functions will be developed; fewer REQM strategies and environmental quality levels will be analyzed. The utility of having a consistent overall conceptual framework is that it enables and forces the analyst to make explicit the assumptions he has to make because of limitations of analytical resources. This expedites reanalysis in the next round of the continuous planning process for residuals-environmental quality management.

DEFINITIONS

Two groups of words and terms are used in describing the approach set forth in this paper. Words and terms in the first group have technical meanings which, in some instances, may differ from common usage of the word or term. Terms in the second group are new in the sense that they are used in this report to describe the residuals management strategy which is the focal point of the paper.

First Group:
—Products
—Non-Product Outputs
—Intermediate Products
—Residuals
Second Group:
—Physical Methods
—Implementation Measures
—Institutional Arrangements
—Residuals Management Strategy

In the first group, products, non-product outputs, intermediate products and residuals are terms used in describing the production process for, and use of, goods and services. In fulfilling the demands for goods and services, producers and suppliers respond by providing certain *products*—i.e. goods and services. In so doing, other outputs result which are not the primary or intended products. These are *non-product outputs*. Non-product outputs may be utilized or discarded depending on their economic value. If utilized, they are *intermediate products;* if discarded, they are *residuals*. The distinction between intermediate products and residuals is a practical one based solely on economic value and *without* consideration of the effect of environmental controls. In other words, residuals are non-product outputs which would not be recycled, reused or recovered unless some type of environmental or pollution control was imposed on the producer.

It should be noted that external factors which change from time to time and which are beyond the control of the producer of goods and services determine whether the non-product output is an intermediate product or a residual. As an example, at a given point in time it may be more profitable for an industry to use virgin raw material than to recover the same raw material that is a non-product output (e.g., virgin iron ore vs. scrap or virgin fiber vs. recycled newsprint). Thus, the non-product output is a residual. Later, due to price increase or unavailability of the virgin raw material, it is profitable to recover and reuse the non-product output which thereby is changed from a residual to an intermediate product. This distinction between intermediate products and residuals is important since it is residuals that are the targets of environmental controls.

In the second group, physical methods, implementation measures, and institutional arrangements are used to describe the components of the residuals management strategy (pollution control strategy) of this report. They are defined in detail since they are the basis for describing the residuals management strategy.

—*Physical Methods:* Technological or structural actions which result in a change of the quantity, type, timing, or spatial location of residuals discharged into the ambient environment and/or improve the assimilative capacity of the natural environment. Examples of physical actions are changes in production process technologies, changes in the operating rate of the production process, treatment of residuals (changing form), in-stream aeration, and so on.

—*Implementation Measures:* Non-structural actions such as laws, regulations and ordinances to induce implementation of desired physical methods. Implementation measures also achieve established goals and objectives consistent with established policies. Examples of implementation instruments include performance and product specifications, emissions (residuals) limitations, zoning, federal funding for treatment plants, accelerated depreciation for pollution control devices, phosphate limitation on home laundry detergents, and so on.

—*Institutional Arrangements:* The established public organizations at all levels which establish goals and objectives, which select, initiate, operate, and enforce physical methods, and which have the authority to identify and adopt implementation measures. Institutional arrangements also include intra-organization and interorganization arrangements. Examples include Federal, State, city, county, regional, and interstate legislative and administrative bodies.

—*Residuals Management Strategy:* A combination of physical methods, implementation measures, and institutional arrangements adopted for the purpose of reducing or eliminating the discharge of residuals into the environment and/or reducing or eliminating their impact if discharged—i.e. achieving environmental quality objectives.

Physical methods may be viewed as the "hardware" as compared to the other components which may be viewed as the "software" of the residuals management strategy.

MATHEMATICAL ANALYSIS OF SOME ECOLOGICAL-ECONOMIC MODELS

M. YA. ANTONOVSKIY and S. M. SEMENOV

The extensive addressing of ecological-economic, as well as purely economic, problems has led in the past 30 years to the appearance of completely new trends in mathematical thought. The founders of these trends were such outstanding mathematicians as J. von Neuman, L. V. Kantorovich, L. S. Pontryagin and R. Bellman. These trends were then developed and spread extensively by their numerous students and followers.

The classical method of modeling ecological-economic systems was the construction of the appropriate differential equations, which approximately describe, given certain hypotheses, real processes. However, quite frequently the attempt to use a well-developed mathematical apparatus prevailed over the competency of its application. Therefore, the theoretical curves obtainable from models unsatisfactorily (even qualitatively) corresponded to reality. This occurred owing to the violation of one of the basic principles of the construction of mathematical models — the principle of adequacy of the mathematical apparatus.

In reality it proves that discrete models (generally speaking, more difficult for their mathematical study) more adequately describe the ecological-economic processes being modeled. The mappings which correspond to discrete processes only rarely coincide with the operations of a shift along the trajectories of differential equations.

For studying ecological-economic systems extensive use is made of the mathematical apparatus of the theory of stochastic processes, the theory of stability, and the theory of optimum control. In these sections of mathematics there have crystallized such concepts as stability, contingency and optimality, which are natural analogues, idealizations of the corresponding biological and ecological-economic concepts.

At present in the mathematical modeling of ecological-economic systems two basic approaches are noted: on the one hand, the construction of such models in which ecological variables are the main disaggregate variables, while economics belongs to these models as aggregate variables that play the role of limiting factors, and on the other hand, there have become widespread the models of economic systems in which the ecological variables are now very aggregated and are limiting factors in the development of production. The widely known Forrester-Meadows global models [1,2] are an example of the latter. Let us also note the indirect consideration of ecological factors in the form of limitations of pollutants, which was done by W. Leontif within his "input-output" model [3]. An analogous indirect consideration of the ecological factors in the economic models of Walras, Arrow-Debray, J. von Neuman [4] and others is very desirable.

Ideally, of course, it is desirable to construct models in which variables of both types are disaggregated. However, right now by flexible combination of models of the two above-described types, we can obtain significantly realistic evaluations for the optimum selection of ecological-economic strategies.

It should be noted that both types of models are of interest from the viewpoint of specific economics. The central question of modern ecology is the question of the optimum and maximum permissible anthropogenic influences on the environment. This question is subdivided into three closely interrelated ones, which form the organic whole of the question — observation of the state of the environment (monitoring), the study of the mechanism and structure of the ecosystems themselves and the direct consequences of anthropogenic influences on the environment. In this report we will treat the first two of the above-formulated questions.

In this paper we examine some mathematical models of ecological-economic systems, and also give a qualitative and quantitative analysis of their features.

In selecting the material, we tried to hold to the following principle: to examine only those models which can provide concrete results to practitioners — economists and ecologists — when there are sufficient data.

In the first model we find a phenomenon in the dynamics of populations, which we call ecological elasticity. The second model makes it possible to state a hypothesis on the existence of an extensive class of complex systems, the dynamics of which can be predicted from the dynamics of the subsystems, which have fewer elements than the entire system and yield a more precise description. The third model is an example of the optimum (from an ecological standpoint) system for observing the size of a population, using the tracking of forest pests as an example.

MATHEMATICAL MODELS OF THE ENTOMOFAUNA (AN ANALYSIS OF MATHEMATICAL MODELS OF THE NICHOLSON-BAILEY TYPE)

Recently extensive studies have been made which are devoted to questions of biological control of pests. As opposed to chemical control of forest pests, which in essence is a periodically repeated destructive measure, biological control is a one-time influence on the ecosystem, which leads to the creation of a stable system of the self-regulation of the size of the pest population, which excludes the possibility of the emergence of outbreaks of the massive reproduction of the pests.

One of the biological methods of controlling pests is the creation of a system of the parasite-host type. The 1932 work of Nicholson [5] already described a system of difference equations, which models the interaction of parasite-hosts. In this work Nicholson numerically revealed in particular the absence of stationary solutions of this system, which according to Lyapunov are stable. He interpreted this fact as the instability of the real ecosystem.

In developing the ideas of Nicholson, Hassel and Varley [6], as well as Watt [7], analyzed specific models and subjected them to a study for stability. A survey of these works can be found in the book of Williamson [8].

In this report we examine our parasite-host model, which contains as special submodels the above-mentioned models. We examine the parasite-host system with a single reproduction per unit of time per year from n to (n+1).

Let y and x be the numbers, respectively, of the host and the parasite, and k be the coefficient of the natural reproduction of the host. Furthermore, let f(x, y) be the portion of hosts not affected by the x parasite. Of course, $0 \gtrsim f \gtrsim 1$. Then the mapping describing the parasite-host system is written in the form:

$$
\begin{aligned}
x_{n+1} &= a(1-f(x_n, y_n))y_n \\
y_{n+1} &= kf(x_n, y_n)y_n
\end{aligned}
\qquad (1)
$$

where (a) is a coefficient having the meaning of the average number of parasites issuing from one affected host (i.e., it takes into consideration the fertility rate and death rate of the parasites).

Special cases of this model are the Nicholson-Bailey model, where $f(x, y) = e^{-\theta x}$, and the Hassel-Varley model, where $f(x, y) = e^{-Qx^{1-m}}$.

The biology of the phenomenon places on f the following limitations:

A. Given a fixed number of hosts with an increase in the number of parasites, the fraction of hosts escaping infestation should decrease, i.e., f is a function decreasing with respect to x.

B. The stationary number of parasites p(y), given a fixed number of hosts y, satisfies the requirement of a monotonic increase according to y. (The existence of a stationary number follows from requirement A and the form of model 1.)

C. The function $x = x(y)$, which is a solution to the equation $f(x, y) = 1/k$, does not increase monotonically according to y.

Theorem 1. Let system 1 satisfy the conditions A, B and C. Then it has a single stationary point (x , y) of the domain $x, y > 0$. This point is found from the solutions of the system of equations $x - p(y\ ) = 0$, $kf(x\ , y\ ) = 1$.

The number of hosts and parasites will fluctuate around x and y , respectively.

For the study of the stationary point for stability let us calculate the Jacobi matrix of the mapping of 1 at the point (x , y).

$$
J(x\ , y\ ) = \left\| \begin{matrix} -ay\ \frac{\delta f}{\delta x}(x\ , y\ ), & a(1-f(x\ , y\ )) - ay\ \frac{\delta f}{\delta y}(x\ , y\ ) \\ ky\ \frac{\delta f}{\delta x}(x\ , y\ ), & kf(x\ , y\ ) + ky\ \frac{\delta f}{\delta y}(x\ , y\ ) \end{matrix} \right\|
$$

The characteristic numbers of the matrix J(x , y) are the roots of the equation:

$$
\lambda^2 - \lambda \left\{ 1 + ky\ \frac{\delta f}{\delta y}(x\ , y\ ) - ay\ \frac{\delta f}{\delta x}(x\ , y\ ) \right\} - aky\ \frac{\delta f}{\delta x}(x\ , y\ ) \Big\} = 0
$$

A sufficient condition of stability, as is known, is the condition $|\lambda_1|, |\lambda_2| < 1$, and of instability $1 < |\lambda_1|$ or $1 < |\lambda_2|$.

If there is given the level of the number A, which characterizes the outbreak of the massive reproduction of the host, i.e., its number when 100% of the trees are being eaten by caterpillars, then we can calculate $y_d(A)$, the lower critical level after which an outbreak arises.

Theorem 2. For any number A there is a number of hosts $y_d(A)$ such that when $y_0 = y_d(A)$ the trajectory of the mapping of 1 with this initial condition will as a result necessarily enter into the domain $y > A$.

The above analysis of a mathematical model of the Nicholson-Bailey type makes it possible to formulate the following conclusions:

1. Decreases in the size of the population of forest pests to lower than some critical level, which arise periodically as a result of anthropogenic and natural causes (weather, fires, etc.), as a consequence lead to outbreaks of massive reproduction. We call this phenomenon ecological elasticity. The critical levels can easily be calculated in each specific model, provided we know beforehand the level of the outbreak, i.e., the 100% eating of the green mass.

2. The existence of the effect of ecological elasticity in the parasite-host model indicates the need to search for the optimum combination of various methods of controlling insect pests: biological, chemical, microbiological. As is apparently evident from the above-cited analysis, the attempts to stabilize the size of the population of insect pests only through the use of parasites are not very promising.

In the appendix we numerically analyze specific models of type 1. The materials of this section are expounded in more detail in work [9].

THE APPROACH TO CREATING BIOLOGICAL METHODS OF PREDICTING THE STATES OF NATURAL ECOSYSTEMS

Natural ecosystems are classical examples of socalled large or complicated systems. In foreign and domestic literature this term is usually understood to mean the systems described by a very large number of variables, the nature of whose interaction at the present stage of development of science we are not able to establish in all its details (and frequently not even approximately). This circumstance, however, does not remove from the agenda the problem of analyzing such systems and, in particular, the problem of predicting their states.

The topicality and importance of such problems as weather forecasting, the prediction of outbreaks of the massive reproduction of forest pests, etc., are known to all. The usual approach to solving problems such as the problem of weather forecasting consists in the maximum detailed continuous following of the state of the atmosphere and the subsequent extrapolation of the available data into the future through the use of statistical methods. This method of forecasting is very uneconomical, since it requires, should we wish to increase its effectiveness, very large expenditures on the creation and maintenance of a network of stationary observation points, as well as on in-depth probing of the upper layers of the atmosphere.

Below we discuss a fundamentally different, strictly biological approach to the problem of predicting the states of natural ecosystems.

The information about the future state of an ecosystem has already been placed in its present state, and namely, it has been encoded in the processes of development of the biological species from which this ecosystem is formed. This is a direct consequence of the developed system of adaptation to a change in the environment, which has been worked out by evolution for biological organisms. After studying this system of adaptation, we will be able to decipher the information about the future of the ecosystem, which has been placed in its present dynamics.

Let us examine a phenomenon of the reflection of the future state of an ecosystem in its present state through a specific example — the example of diapause.

In biology it is known that populations of species of some biological organisms, which are ready for the start of the process of reproduction, draw out this process in time. This phenomenon of asynchronization of the moments of reproduction of species in a population has been called diapause.

Diapause is widespread among Lepidoptera, Hymenoptera, Coleoptera and Diptera, as well as among seeds of dycotyledonous plants.

Since diapausing species are destroyed by biotic and abiotic factors [10-13], and also waste energy resources [14], the biological significance of diapause for a long time was unable to be explained satisfactorily.

In work [15] S. M. Semenov demonstrates on the basis of very general assumptions that such phenomena can theoretically be explained by using the stochastic principle of the optimality of progeny.

As preceding examples of the use of the principle of the optimality of progeny as a consequence of natural selection we can cite the works of F. N. Semevskiy [16], Cohen [17], and Lewontin and Cohen [18].

Let us have A new cocoons, and let the problem consist in distributing this set into N groups (we believe that diapause cannot last more than N years for physiological reasons),

$$\lambda_1 A, \ldots, \lambda_i A, \ldots, \lambda_N A,$$

from which fly away imagoes in 1, 2, . . . , N years respectively, and the set $\lambda_1, \ldots, \lambda_N$, $\Sigma\lambda_i = 1$, $\lambda_i \geqq 0$, should be selected such that the mathematical expectation of the logarithm of the number of progeny of this group would be the maximum.[*] We will calculate the contingency of the environment by two means. Let a_i be the probability that the pupa will live to the ith year. Of couse, $a_1 \geqq a_2 \geqq \ldots \geqq a_N$, $a_1 = 1$. Furthermore, let $p(X_1, \ldots, X_N)$ be some random process that models the contingency of the conditions of the existence of the organisms being examined in the active phase ($X_i a_i A$ is the progeny of one pupa which has lived through the ith winter). With respect to p we will assume that:

$$0 < X_i < \infty \text{ for any } i = 1, \ldots, N \text{ and,}$$

$$p(X_1, \ldots, X_i, \ldots, X_j, \ldots, X_N)$$
$$= p(X_i, \ldots, X_j, \ldots, X_i, \ldots, X_N) \text{ for any } 1 \lesssim i, j \lesssim N.$$

It should be noted that all the random processes known to the authors, which have been used in models of this type, belong to the class we are examining.

Thus, we will assume that the optimum behavior of the population corresponds to the optimization of the mathematical expectation of the logarithm of the number of progeny of this set of species, i.e., the optimization of the functional

$$F(\lambda_1, \ldots, \lambda_N) = M\left\{ \ln \sum_{i=1}^{N} \lambda_i A a_i X_i \right\}, \ \lambda_i \geqq 0, \Sigma \lambda_i = 1.$$

Thus we assume that the population adapts to the winter death rate, while the contingency of the environment in the active phase is calculated only on the average. This corresponds to the biology of the phenomenon [16].

THE EXISTENCE OF AN OPTIMUM STRATEGY

It is easy to see that the functional F is defined for the compact K, and namely for the simplex:

$$K = \{(\lambda_1, \ldots, \lambda_N) \mid \lambda_i \geqq 0, \Sigma \lambda_i = 1\}.$$

Given each set $(X_1, \ldots, X_N)$ the functional:

$$(\lambda_1, \ldots, \lambda_N) \longrightarrow \ln(\Sigma \lambda_i A a_i X_i)$$

is continuous at K. It is clear that the operation of taking the mathematical expectation for the sets $(X_1, \ldots, X_N)$, i.e., the operation of integration for the vector parameter $\overline{X} = (X_1, \ldots, X_N)$, given reasonable assumptions on the density p, again leads us to a continuous function. Thus F is a continuous function for the compact and, consequently, has a maximum and reaches it at K.

Uniqueness of the Optimum Strategy $(\lambda_1^{opt}, \ldots, \lambda_N^{opt})$

Given any set $X_1, \ldots, X_N$ the functional

$$F_{\overline{X}}(\lambda_1, \ldots, \lambda_N) = \ln(\Sigma \lambda_i A a_i X_i)$$

is a strictly concave functional, i.e.,

$$F_{\overline{X}}\left(\frac{\lambda'_1 + \lambda''_1}{2}, \ldots, \frac{\lambda'_N + \lambda''_N}{2}\right) >$$
$$\tfrac{1}{2}\left(F_{\overline{X}}(\lambda'_1, \ldots, \lambda'_N) + F_{\overline{X}}(\lambda''_1, \ldots, \lambda''_N) \right)$$

This property will be retained after taking the mathematical expectation, i.e., after averaging this inequality with the weight p. Consequently, F is a strictly concave functional and, hence, has at K only one maximum.

MONOTONY OF THE OPTIMUM STRATEGY

Let us show that $\lambda_1^{opt} \geqq \lambda_2^{opt} \geqq \ldots \geqq \lambda_N^{opt}$. For this we will prove, for example, that $\lambda_1^{opt} \geqq \lambda_2^{opt}$. As will be evident from the proof, it is literally correct for the case $\lambda_i^{opt} \geqq \lambda_{i+1}^{opt}$ for any $i = 1, \ldots, N-1$.

Thus, let $(X_3, \ldots, X_N) = \overline{u}$, $p(\overline{u}) = \sum_{i=3}^{N} \lambda_i A a_i X_i$.

Then, owing to property b) of the process p we have the chain of equalities

$$F(\lambda_1, \ldots, \lambda_N) = \int_0^\infty \ldots \int_0^\infty \ln\left(\sum_{i=1}^{N} \lambda_i a_i X_i A\right) p(\overline{X}) dX_1 \ldots dX_N$$

$$= \int_0^\infty \ldots \int_0^\infty p(\overline{X}) \ln(\lambda_1 a_1 A X_1 + \lambda_2 a_2 A X_2 + p(\overline{u})) \, dX_1 dX_2 dX_3 \ldots dX_N$$

$$= \tfrac{1}{2} \int_0^\infty \ldots \int_0^\infty \Big\{ \ln(\lambda_1 a_a A X_1 + \lambda_2 a_2 A X_2 + p(o)) + \ln(\lambda_1 a_1 A X_2 + \lambda_2 a_2 A X_1 + p(u)) \Big\} p(\overline{X}) d\overline{X}.$$

Let us transform the expression in braces to the form

$$\ln[\, p^2(\overline{u}) + A p(\overline{u}) (X_1 + X_2) (\lambda_1 a_1 + \lambda_2 a_2)$$
$$+ A^2 \{ X_1 X_2 (\lambda_1^2 a_1^2 + \lambda_2^2 a_2^2) + \lambda_1 \lambda_2 a_1 a_2 (x_1^2 + x_2^2) \}].$$

---

[*] The substantiation of precisely this selection of the integral functional can be found in works [3,17,18].

It is easy to show that given $\lambda_1, \lambda_2, a_1, a_2 \geq 0$, $a_1 \geq a_2, \lambda_1 < \lambda_2$,

$$\lambda_1 a_1 + \lambda_2 a_2 < \lambda_2 a_1 + \lambda_1 a_2$$
$$\lambda^2 a^2 + \lambda^2 a^2 < \lambda^2 a^2 + \lambda^2 a^2$$

Consequently, given the permutation (λ_1, λ_2) —— (λ_2, λ_1) the functional F is always increasing.

Hence it follows that given any $1 \lesssim i,j \lesssim N$ from $a_i < a_j$ it follows that $\lambda_i^{opt} < \lambda_j^{opt}$,
from $a_i > a_j$ it follows that $\lambda_i^{opt} > \lambda_j^{opt}$,
from $a_i = a_j$ it follows that $\lambda_i^{opt} = \lambda_j^{opt}$.

In particular, inasmuch as $a_1 \geq a_2 \geq \ldots \geq a_N$, then $\lambda_1^{opt} \geq \lambda_2^{opt} \geq \ldots \geq \lambda_N^{opt}$.

NONTRIVIALITY OF THE OPTIMUM STRATEGY

If a random process is trivial, i.e., it consists in all of one trajectory $X_1 = X_2 = \ldots = X_N = C$, then owing to $a_1 \geq a_i$

$$\Sigma \lambda_i a_i AC \leq \Sigma \lambda_i a_1 AC = a_1 AC.$$

It is clear that in this case the optimum strategy would be the strategy $\lambda_1 = 1$, $\lambda_2 = \lambda_3 = \ldots = \lambda_N = 0$.

From this examination it quickly follows that given any determinate process the optimum strategy has the nature of an impulse.

Let us show that in a significantly stochastic case the optimum strategy can be fundamentally different.

Indeed, when $a_1 = a_2 = 1$, among the double-pulse strategies (i.e., for which $\lambda_3 = \ldots = \lambda_N = 0$) the optimum would be the strategy $\lambda_1 = \lambda_2 = \frac{1}{2}$; consequently:

$$M\{\ln(a_1 AX_1)\} < M\{\ln(\tfrac{1}{2}a_1 AX_1 + \tfrac{1}{2}a_2 AX_2)\}.$$

Furthermore, this inequality remains correct when a_2 is close to 1. Consequently, in this case the optimum strategy cannot be single-pulse, since the strategy $\lambda_1 = \lambda_2 = \frac{1}{2}$, $\lambda_3 = \ldots = \lambda_N = 0$ is better than the latter.

Above we strictly demonstrated within a quite extensive model that from the stochastic principle of the optimality of progeny there can theoretically be obtained the existence of the effect of the asynchronization of the moments of reproduction of species in some population. Let us note that by remaining within the framework of deterministic notions we could not have obtained this effect.

On the basis of the obtained results we can assert that evolution is capable of developing adaptation not only to determined, but also to random processes. Thus, we believe it necessary to supplement the conception of A. S. Monchkuskiy [19].

The optimum strategy, the qualitative properties of which we have studied, can be found by solving the very complicated task of stochastic approximation using a computer.

Thus, the phenomenon of diapause of species, or more broadly, the phenomenon of asynchronization of development, can be considered completely explained. Moreover, it is possible to precisely explain theoretically the strategy of a type under the conditions of a random environment with given statistical properties.

In conclusion let us note that having studied the dependence of $\lambda_1, \ldots, \lambda_N$ on the probabilities $a_1, \ldots, a_N$, which depend on the future state of the environment (weather, the presence of predators, etc.), it is theoretically possible to solve the reverse problem — the prediction of the state of the environment according to the nature of the development and reproduction of certain biological species.

For example, weakly expressed diapausing means a very low winter death rate of insect pupas, while strong expressed diapausing means a high one. The winter death rate among insect pupas is caused by a very insignificant number of factors. And when specific ecological research makes it possible to consider the influence of biotic factors, small diapausing may be connected only with hydrometerological conditions of the existence of the species.

The indicated approach to predicting the states of natural ecosystems is very effective for the following reasons:

- —The phenomenon of adaptation of biological species to changes in the sphere of habitation among mass species is expressed clearly enough. For example (see work [16]), frequently observable fluctuations of the proportions of diapausing species from 1% to 20% of the total insect population.
- —The obtainable prediction is of a regional nature, since it is constructed on the basis of the behavior of the population, which geographically is usually entirely localized.
- —The proposed method of prediction is very economical, since data on the behavior of the population can be obtained from already existing stationary observation points. In practice the expenditures on the organization of this type of system of tracking promise to be very insignificant.
- —The information being accumulated intensively at the stationary point will undoubtedly be a powerful stimulator of further fundamental ecological studies on the dynamics of species of forest insects and its connection with the state of the sphere of habitation.

In conclusion we once again turn our attention to the following thesis: in every real complex biological system there is a small number of comparatively simple subsystems, through the observance of whose dynamics it is possible to compile a prediction of the state of the entire system. Let us call such systems the basic dynamic components of the complex system.

THE OPTIMUM SYSTEM FOR KEEPING TRACK OF THE SIZE OF POPULATIONS OF FOREST PESTS

The ecological and economic significance of this monitoring is important because outbreaks of massive reproductions of the indicater populations occur on areas of several tens of millions of hectares. There has been developed an optimum system of monitoring the density of populations of conifer and leaf boring insects (A. I. Vorontsov, G. E. Insarov and others). Relying on the mathematical apparatus and modern computers, this monitoring is designed for operational decision-making on controlling the indicated populations.

Such a system is proposed for keeping track of the density of the population of forest insects, which makes it possible to concentrate efforts on the direct taking of probes at a small and economically justifiable number of stationary observation points. In this way the effectiveness of the work of forest protection workers is significantly increased. The decision to prescribe or not prescribe forest insect pest control on the territory of any economic unit is made on the basis of information on the state of the entire population in the territory surrounding the unit. This model of monitoring is constructed on the basis of data about the spatial and time distribution of the following types of insects:

- Green oak leaf roller moth (Moscow Oblast, 1962-71, GDR, 1957).
- Stellate web-spinning sawflies (Krasnoyarskiy Kray, 1961).
- Gypsy moth (European part of the RSFSR, 1891, 1924, 1938-39, 1946, 1954, 1956).
- *Malacosoma distria* Hbn. (Minnesota, USA, 1949-54).
- *Choristoneura fumiferana* Kelm. (Quebec, Canada, 1946-57).

The economic criterion determining the recommended policy of pest control in a region consisted in minimizing the overall average expenditures per annum per hectare of the territory under examination. These expenditures $K(s, g)$ were composed of three components:

- $W(s, g)$ is the average loss in territory and time from the pest and control of it (we have in mind the environmental pollution accompanying chemical control);
- $kb\frac{1}{100s^2}$ is the cost for taking probes on one hectare (k is the proportion of the area of the region occupied by forest and belonging to a fixed layer; b is the cost of a probe on one hectare);
- $C(g, s)$ is the cost of sending the data to a computer center and their processing.

The variables s and g characterize the territorial geometry of monitoring and should be optimized (see in more detail below).

The greatest difficulty in computing the functional $K(s, g) = W(s, g) + kb\frac{1}{100s^2} + C(s, g)$ consists in calculating the summand $W(s, g)$ which we are setting about to analyze.

The damage from forest pests consists of two components, M_1 and M_2, where M_1 is the damage from the loss of weight increase, and M_2 is the loss from desiccation (which occurs in one case out of 100, when the wood is entirely eaten). Here the average loss $U(Y)$ is calculated by the formula:

$$U(Y) = (1 - 0.01\,\gamma)M_1 + 0.01\,\gamma M_2,$$

where γ is the probability of 100% eating taking into consideration the limitation of food, and Y is the density of the pest population in the number of eggs /100 g of fresh leaves (or per unit length of the branch, etc.). Biological practice makes it possible to examine the density of the population $Y(\bar{t})$ over the land surface as a two-dimensional random field.

There is a critical density of the population Y_c such that if $\bar{Y} \geqq Y_c$, a decision is made on prescribing chemical control. If T is the cost of control per hectare, then Y_c is defined as the root of the equation:

$$U(Y_c) = T.$$

In determining the magnitude of T, besides direct expenditures for control (the cost of chemicals, flying time, work force, etc.), the harmful effects of chemical control on the forest ecology are taken into consideration. The consideration of all these factors may make considerable adjustments in the distributional representation of chemical control of forest pests as a profitable economic measure in all instances.

Let us examine in more detail the method of calculating the magnitude of $U(Y)$. If we examine the value of $Y(\bar{t})$ in the layer, i.e., for example, in the planting of a definite age and composition, this will be expressed mathematically in the fact that the correlation function depends only on distance, then the field of deviations $X(\bar{t}) = Y(\bar{t}) - M\,[Y(\bar{t})]$ will be homogeneous and isotropic, i.e.,

$$\mathrm{cor}\,[X(\bar{t}_1), X(\bar{t}_2)] = \epsilon\,(|\bar{t}_1 - \bar{t}_2|).$$

The autocorrelation function of the field $X(\bar{t}) + \Delta(\bar{t})$, where $\Delta(\bar{t})$ is the field of errors of measurement (it is believed that at different points they are not correlated), was selected in the form:

$$K(\tau) = \begin{cases} 1, \tau=0 \\ \dfrac{D\exp(-\varepsilon\tau)}{\lambda^2+D}, \tau\neq 0, \end{cases}$$

where $\varepsilon=0.00052$, λ^2 is the dispersion of the field of errors, D is the dispersion of the field $X(\overline{t})$. The autocorrelation function for $X(\overline{t})$ was selected, correspondingly, in the form $\exp(-\varepsilon\tau)$. These functions conveniently approximated the available factual data.

Let us briefly describe the system of tracking. The entire territory on which outbreaks of massive reproduction are possible is broken down into basic squares with a side of s km, at the center of which systematic measurements of the density of the population are made. Each basic square is broken down into 25 additional squares. At every moment in time the evaluation of the deviation from the mathematical expectation of density of the population at the center of each additional square is obtained as a function of the corresponding deviations measured at the same moment in time at the center of the basic squares surrounding the basic square in which the additional square being examined is located. The basic squares, the measurement at whose center is used for evaluating the density of the population for the given additional square, should all together form a square consisting of an odd number of basic squares; the central basic square contains the given additional square. If we number the basic squares with the pairs of numbers (k, p), $k=1, \ldots, C_g$; $p=1, \ldots, C_g$, and the additional squares with the pairs of numbers (r, q), $r=-2, \ldots, 2$, $q=-2, \ldots, 2$, then given fixed C_g and s the evaluations for the field $X(\overline{t})$ at the centers of the additional squares are obtained in the form:

$$X(s, g)_{r,q} = \sum_{k=1}^{C_g} \sum_{p=1}^{C_g} a(s,g)_{r,q;k,p} \cdot X_{k,p}$$

The coefficients a(s, g) are chosen on the basis of the principie of maximum likelihood.

The selection of the side of the basic square s and the number C^2_g of the basic squares used for the evaluation, is made on the basis of the above-mentioned criterion of optimality, proceeding from the minimization of the average damage caused to forestry. The numerical treatment of the examined model, which was carried out by G. E. Insarov [12] on the BESM-6 computer, showed that the optimum network of the system for keeping track of the densities of forest pest populations should be the following: the observation centers should be located at the center of basic squares with a side of 64 km, while the magnitude of the parameter g should be four.

The proposed system of calculating conifer and leaf boring insects makes it possible to sharply increase the accuracy of the calculation while significantly decreasing its total cost.

CONCLUSION

Thus, the proposed system for keeping track of the density of forest insect populations makes it possible to concentrate our efforts on the direct taking of probes at a small, economically justifiable number of stationary observation points and thereby, significantly increase the effectiveness of the work of forest protection workers. The decision on prescribing or not prescribing forest insect pest control on the territory of an economic unit is made on the basis of information on the entire population from previous years and operational information obtained from the territory surrounding the unit.

The application of the developed system of calculating the conifer and leaf boring insects on areas of outbreaks of massive reproduction will create new prospects for centralized forest protection.

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